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COMPREHENSIVE EXPERIMENTAL DESIGN PLAN TO RELATE POLLUTANT SOURCES TO ACIDIC DEPOSITION

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16. ABSTRACT

Because verifiable numerical models that incorporate all processes determining the dispersion, transformations, and deposition of emitted pollutants associated with acidic deposition from the atmosphere are only now under development, it was deemed worthwhile to determine whether other methods might be available to empirically relate acidic deposition to precursor emissions. After determining that the most promising direct approaches, large-scale source modulation and use of reactive tracers would not be feasible, an indirect experimental plan named the combined experimental approach was developed. This approach consists of three major components: long-range tracer experiments; short-range experiments, including reactive tracers, local deposition experiments, and local source modulation; and routine monitoring of aerometric parameters. Analyses of data would provide estimates of source contributions to deposition at receptor sites. The collected data would also be used for developing and testing upgraded regional models and model components.

This report describes the workshop used to develop the general experimental design and the follow-up analyses of the various components. Some of the design sections describe experiments that will yield data for evaluation of acid deposition models. Finally, the costs of the various experimental efforts are described.

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PREFACE

This document presents the design of an experimental program to relate acidic deposition in source regions to precursor emissions. TRC prepared the document in its final form and assumes responsibility for the content. Acknowledgement is given to written contributions of those named on the title page and the helpful discussions with all of the Workshop Participants who are listed in Appendix B. Uncertainties of various experimental aspects are examined in a companion report.

The objectives of the project were to design an experiment to relate empirically mass transfer from acid pollutant source areas to acidic deposition areas and to provide a data base from the field study to aid in model development and evaluation. The Electric Power Research Institute sponsored a study with objectives similar to the first listed. Joint review meetings were held by representatives of the National Acid Precipitation Assessment Program (NAPAP). It was decided from the findings of both projects, that the probability of developing reliable empirical source-receptor relationships was small and further planning for the program was suspended. Planning was instituted for field studies to provide data for model evaluation under a new project within NAPAP.

This research has been funded as part of the National Acid Precipitation Assessment Program by the Environmental Protection Agency.

ABSTRACT

Because verifiable numerical models that incorporate all processes determining the dispersion, transformations, and deposition of emitted pollutants associated with acidic deposition from the atmosphere are only now under development, it was deemed worthwhile to determine whether other methods might be available to empirically relate acidic deposition to precursor emissions. After determining that the most promising direct approaches, large-scale source modulation and use of reactive tracers would not be feasible, an indirect experimental plan named the combined experimental approach was developed. This approach consists of three major components; long-range tracer experiments; short-range experiments, including reactive tracers, local deposition experiments, and local source modulation; and routine monitoring of aerometric parameters. Analyses of data would provide estimates of source contributions to deposition at receptor sites. The collected data would also be used for developing and testing upgraded regional models and model components.

ACRONYMS

ACURATE - Atlantic Coast Unique Regional Atmospheric Tracer Experiments

ADMP - Acid Deposition Modeling Project

AMBIENS - Atmospheric Mass Balance of Industrially Emitted and Natural Sulfur

APIOS - Acid Precipitation in Ontario Study

CAPMoN - Canadian Air and Precipitation Monitoring Network

CAPTEX - Cross Appalachian Transport Experiment

COMPEX - Comprehensive Experiment

DIAL - Differential Absorption Lidar

MAP3S - Multistate Atmospheric Power Production Pollution Study

MATEX - Massive Atmospheric Tracer Experiment

MCS - Mesoscale Convective System

NAPAP - National Acid Precipitation Assessment Program

NEDS - National Emission Data System

NTN - National Trends Network

OAQPS - EPA Office of Air Quality Planning and Standards

PRECP - Processing of Emissions by Clouds and Precipitation

SLAMS - State and Local Air Monitoring System

STORM - Stormscale Operational and Research Meteorology Program

SURE - Sulfate Regional Experiment

UAPSP - Utility Acid Precipitation Study Program

EXECUTIVE SUMMARY

The comprehensive field study plan to relate pollutant sources to acid deposition was developed under the sponsorship of the U.S. Environmental Protection Agency Environmental Sciences Research Laboratory by a research team headed by TRC Environmental Consultants, Inc. and consisting of TRC, Brookhaven National Laboratory (BNL), and Systems Applications Inc. (SAI).

The objectives of the plan are to design experiments which will:

1) Relate empirically the mass transfer from acid pollutant (and precursor) source areas to acidic deposition.
2) Provide a data base to aid in the development and evaluation of regional acidic deposition models.

In designing these experiments, TRC convened a workshop to provide a consensus opinion on potential experimental concepts and guidance to the team on details of the design. The workshop was held at Brookhaven National Laboratory in May 1984.

Workshop participants identified a number of experimental approaches which could serve as the core of the program. The most technically promising of these approaches for directly determining source attribution with confidence were source modulation experiments and isotopic reactive tracer experiments. Several indirect approaches for determining source attribution were also identified. They included inert tracers, emulators, process evaluation, and integration of existing data. Subsequent to the workshop, it was determined that economic and logistical constraints would not permit source modulation experiments on a regional scale. The reactive tracer experiments were likewise determined to be infeasible due to the expected adverse public reactions to releases of an unstable (radioactive) isotope and the limited availability and high cost of stable isotopes.

Because of constraints on direct experiment approaches, the design team decided to pursue an indirect experimental approach, which for this plan, is named the combined experiment approach. The name is meant to convey the concept of a collection of interactive experimental components which together provide data for determination of quantifiable source/receptor relationships and a data base for model evaluation.

It is expected that relationships developed from the combined experiment will provide an improvement on current source attribution techniques, but uncertainties associated with the combined experiment cannot be quantified without pilot and uncertainty studies. Because of the complexity of the combined experiment, the adequacy of the experiment can not be determined at this time. To compensate for not having an estimate of uncertainties, the experimental plan uses redundancy of tasks in staged experiments. The staged approach provides pilot studies prior to the main experimental program to refine techniques, estimate uncertainties and establish feasibility as well as providing the sponsor with milestones for program control. Results of initial studies are given in this report.

The combined experiment is designed on the basis of a transmittance approach consisting of three major components. Transmittance refers to the method by which source attribution is determined. First, the vertical pollutant distribution in the vicinity of a receptor is determined from the fractional transmittance of mass as it is transported between a source and receptor. In this context, fractional transmittance is that fraction of pollutant mass which is not lost en route due to deposition. Second, the mass distribution in combination with the local deposition rate determines the contribution of a source to deposition at a receptor. Fulfilling the data needs of the transmittance approach and the secondary objective of providing a data base for model evaluation, leads to a program with the following components:

Long Range Tracer Experiments

The major objectives of the long range tracer study are to simulate transport and dispersion of pollutants using inert tracers and to determine the mass distribution and mass balance of the tracers in a receptor area. Tracer releases will be made at major emission source areas. These will be selected for study on the basis of SO_2 emissions and forecast meteorological conditions (i.e. expected transport routes). The source areas are located 500 to 1000 km from the Adirondacks Region of New York State which was identified as the primary receptor area for the study although alternative areas could be selected as the focus of the experiments. From these source areas, inert tracers will be released and tracked by means of a ground network of sampling sites throughout the Northeast. A fine resolution ground level sampling grid will be established in the Adirondack Region where aircraft sampling will be conducted to support studies of deposition and transmittance in a small area.

Short Range Experiments

A series of short range experiments is proposed to provide information on plume depletion. This is an important process in the transmittance approach. Current estimates are only available on a local scale and are associated with a high degree of uncertainty. To overcome these uncertainties, a combination of three types of experiments are proposed:

- Reactive Tracer Deposition Experiments - Sulfur-34 tracer studies will be performed to provide information on deposition and plume depletion. The experiments will represent a variety of meteorological and surface conditions. Experiments will include releases of sulfur-34 and two additional inert tracers. The tracer samples will provide deposition estimates by plume depletion and tracer ratio techniques.

- Deposition Experiments - Experiments will be conducted to determine deposition rates using fixed deposition monitoring sites in conjunction with aircraft eddy correlation techniques for ozone. Fixed site data will be used to determine the relationships of ozone and sulfur and nitrogen oxide fluxes. These data will then be available for use in extrapolating aircraft ozone eddy correlation measurements to estimate sulfur and nitrogen oxide deposition for large areas.
- Source Modulation Experiments - The last type of short range experiments proposed are local source modulation experiments. Data from these studies will provide a direct measure of local source attribution and plume depletion as a test for derived source/receptor relationships.

Routine Monitoring and Support Data Collection

This component of the combined experiment will provide the primary data base for model evaluation. It will provide wind and concentration data to help determine transport trajectories and transmittances associated with long-range transport. In addition, the data will be used to study the variability of acidic species and precursors as a function of meteorological and emissions patterns and to provide a historical perspective for these patterns relative to past or ongoing programs. An important role of the data collected under the routine monitoring component will be to provide a limited data set for analysis of the chemistry of deposition processes. Support meteorological and emissions data from other programs will be collected as part of this component.

Analysis

Analyses of the data collected by the three components will characterize deposition episodes. More importantly they will provide fractional transmittance functions, tracer transport statistics, and deposition estimates. Combination of these derived values will provide an estimate of the mass arriving at a receptor and the potential for depositing that mass, thus completing the source/receptor relationships.

The combined experimental program is designed to meet the data requirements of a transmittance approach. Data collected under the program will also be sufficient for additional parallel analyses including analyses using upgraded versions of current regional models, and analyses by statistical inference.

The plan utilizes some untested methods and unproven combinations of techniques. Therefore, success of the design must be gauged in pilot experiments and uncertainty assessments examining these approaches.

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SECTION 1

INTRODUCTION

A comprehensive field study plan to relate pollutant sources to acid deposition has been designed by TRC Environmental Consultants, Inc., with the assistance of Brookhaven National Laboratory and Systems Applications Inc. this report provides the details of this plan in meeting the objectives outlined by the Environmental Protection Agency.

1.1 Background and Objectives

The concept of a comprehensive experiment for relating the sources of pollutants and acidic deposition was introduced to the general scientific community in a memorandum titled "An Experimental Determination of Sources of Acidic Deposition in the Eastern U.S. and Southeastern Canada" (January 1983), by Gary Foley, U.S. Environmental Protection Agency (U.S. EPA) and Glenn Hilst, Electric Power Research Institute (EPRI). The basic motivation for such an experimental program is that although gradual progress is being made in the experimental determination and theoretical description of the processes involved in acid deposition, alternatives must be found more rapidly to satisfy regulatory needs relative to acid deposition. This report describes experiments and analyses aimed at providing a series of empirical source/receptor relationships at a known level of uncertainty rather than simulation models based on a complete physical and chemical understanding of the acid deposition process.

In the absence of a complete theoretical understanding of the relationships of emissions and deposition, this concept is strongly dependent on an experimental design to define source/receptor relationships, the uncertainty levels of measurements, and the effects of such uncertainty on the final empirical relationship. The acceptability of an experimental design is based on the judgment of whether uncertainty levels can be controlled and whether the anticipated error bands are sufficiently small to provide a meaningful result for devising control strategies over the distance scales of interest. Although a distance scale of concern cannot be specified a priori with confidence (indeed the determination of distance scale would be an objective), the proposed experiments to define source/receptor relationships will be concerned with distances up to 1000 km or more.

Confirming uncertainty levels is a difficult challenge and may not be possible within the program constraints. An empirical source/receptor relationship can be thought as one type of model. Although firmly based in data resulting from the measurement program, it is also limited in that any evaluation of the generality of the model requires an independent data set.

Design and feasibility studies for a possible joint EPA/EPRI comprehensive experiment have been undertaken by both organizations independently. In March 1984, EPA contracted TRC Environmental Consultants to independently prepare a field study design to meet the following objectives:

1. To relate empirically mass transfer from acid pollutant (and precursor) source areas to acidic deposition areas.
2. To provide a data base from the field study to aid in the development and evaluation of regional acidic deposition models.

In November 1983, EPRI contracted with a team headed by Environmental Research and Technology to prepare field study designs to meet the following objectives:

1. To establish, for the present configuration of sources, reliable estimates of the amount of acidic deposition in any part of the experimental region that is attributable to anthropogenic sources in any other part of the region.
2. To provide an empirical basis for estimating the reduction of acidic deposition in any area resulting from specified reductions in source emissions in any other area.

The EPRI objectives, through the Massive Tracer Experiment (MATEX), are designed to provide understanding of the relationship of source emissions and deposition under current emissions patterns and meteorology, as well as the changes on deposition which would occur if the emission patterns were changed. The EPA objectives under the Comprehensive Experimental Program (COMPEX) are somewhat more restrictive. They are intended to examine deposition resulting from the current source configuration and to provide a data base for model evaluation. The models tested with this data base could then be used to estimate the impacts of future emissions changes.

1.2 Selection of Approach

In principle, a variety of approaches may be taken toward meeting the EPA objectives. To gain a broad input into the formulation of these conceptual approaches, TRC convened a workshop at Brookhaven National Laboratory in May 1984. Participants in the workshop consisted of representatives from a number of organizations concerned with the development of source/receptor relationships. The intent of the workshop was to reach a consensus on the best experimental approach to fulfill the program objectives and to provide guidance to the design team.

The discussions at the workshop first provided a list of potential designs. The following summarizes these designs and provides comments on the advantages or disadvantages of each:

1. Isotopic Tracer Experiment - Reactive, isotopic tracers allow the simulation of all aspects of deposition, transport, diffusion, and chemical transformation. Releases and sampling of a sulfur isotope tracer as SO_2 would provide an initial source term and concentration and deposition measurements from which a transfer function could be directly calculated.

Advantages

- Techniques provide a direct method of estimating transfer functions.
- Sulfur-35 is a reasonably priced tracer.
- Isotopes can be made by known technology.
- Sulfur-35 can simulate sulfur-32 transformations and deposition.

Disadvantages

- Isotopes have had limited prior use as tracers.
- An insufficient number of isotopes is available for a multisource problem.
- There would be social and political objections to releases of radioactive materials at any level.
- High costs of sulfur-34, sulfur-36, and nitrogen-15 preclude their use as long range tracers.

2. Source Modulation - Source modulation is the modification of emissions levels at a selected group of sources to determine the response in the deposition and concentration levels at potentially affected receptor sites.

Advantages

- Modifications in emissions for testing would produce the effects similar to emissions controls.
- Methods are direct and simple in concept.

Disadvantages

- Detectable responses require large widespread emissions modifications.
- Costs and plant modifications needed to reduce emissions to an adequate level may not be acceptable.
- Difficulties exist in identifying identical meteorological conditions for modification/ premodification comparisons.

3. Inert Tracer Experiments - These tracer experiments simulate pollutant transport and dispersion without losses due to chemical transformations or deposition.

Advantages

- Several tracers are available for long range studies, and additional tracers are available for short range studies.
- The sampling technology has been proven.
- Tracer costs are reasonable.
- Unambiguous information on transport and dispersion is provided.

Disadvantages

- Experiments provide no direct method of estimating losses of material or estimating deposition.

4. SO$_2$ Emulators - In view of limitations on isotopic tracers which can simulate all aspects of sulfur oxide behavior, a proposed alternative is to use materials which simulate particular aspects of the acidic deposition processes (for example, SO$_2$ solubility).

   Advantages - Techniques provide information on individual processes involved with acidic deposition.
   - Potential exists for more controllable experiments at lower costs.

   Disadvantages - Assumptions and generalized results are required for integration of components into source/receptor relationships.
   - Emulators are not now available and would require significant development effort.

5. Transmittance Factors - The transmittance factor approach provides information on deposition by determining the balance between mass transported in and out of areas. The approach combines a study of non-reactive tracers for determining transport and dispersion climatologies with a deposition/transformation "climatology" from short range reactive tracer studies.

   Advantages - Methods make efficient use of limited tracer resources.

   Disadvantages - Difficulties exist in obtaining sufficient accuracies for pollutant measurements and tracer fluxes.

   - Uncertainties can be compounded in applying short range deposition and transformation information to results from the long range non-reactive tracer experiments.

6. Process Validation - Process validation is similar to the approach taken by more process oriented acidic deposition research in providing experiments to understand significant deposition processes by component and combining the results into a series of source/receptor relationships.

   Advantages - Methods provide directed research for solution of more tenable problems.
   - Data are provided for model evaluation.

   Disadvantages - Process validation duplicates efforts in ongoing research programs.
   - Difficulties occur in integrating results into source/receptor relationships within acceptable and known uncertainty levels.

7. Integration of Existing Data - A suggestion was made to perform a complete evaluation of existing meteorological, air quality and precipitation chemistry data with the objective of determining source/receptor relationships.

   Advantages - Data are available without the need for a field program.

   Disadvantages - Data sets are incomplete.
   - No direct measure of source attribution is provided.

In practice, an experimental design might consist of only a single type of study or alternatively a combination of several concepts. Discussions at the design workshop refined the list of alternatives based on technical merit and recommended, as a first priority, isotopic tracer studies as the most direct and least ambiguous approach. The reactive tracer experiment was the consensus choice of the workshop participants from the perspective of providing a direct and scientifically defensible answer to questions of source attribution. Two other options included source modulation and a combined experiment representing the best elements of several alternatives. After the workshop, a design team consisting of TRC, Brookhaven National Laboratory, Systems Applications, Inc., and consultants Drs. Donald Stedman and Boris Weisman, worked to develop a plan for these concepts.

Subsequent investigations have shown that the large scale source modulation experiment will not be feasible because of the extremely high costs associated with modulation at a level which will be experimentally measurable. The two remaining experimental options, reactive tracer and combined experiments, were revised. Work on a plan for an isotopic tracer experiment was begun but was terminated when it was determined that the radioactive tracer releases would be unacceptable within EPA and that stable reactive tracer experiment would be limited by cost or availability of the tracer. The combined experiment, a design which combines many of the better features of the alternatives, is summarized in the following subsection. The plan was designed with priority given to the first objective which is developing empirical source/receptor relationships. Development of experiments to provide a data base for model evaluation was considered secondary and the data base a by-product of the first objective. An experimental design for evaluation of a specific model would be more limited in scope and could be obtained with modifications to the combined experiment plan.

The combined experiment is limited in its ability to meet the primary objective of the program. It does not provide a confirmed technique for determining source/receptor relationships with defined and controllable uncertainty levels. Extremely variable fields of pollutant and meteorological parameters, in combination with the developmental nature of some of the measurement techniques, leave open the questions of whether the uncertainties associated with analysis of measured data will be sufficiently small to make the combined experimental program feasible. These real concerns prompted the design to be written with some redundancy in tasks, and with experiments in progressive stages. Redundancy takes on an engineering definition and requires that the design include alternative approaches and tasks to serve as back-up techniques in the case of a failure of a component. It is also a means of confirming results to reduce uncertainty. The staged approach can be defined as a progression of steps where the stages of the program represent studies designed to determine the feasibility of various components and the entire program in meeting the comprehensive design objectives. The stages of the approach include:

- initial experimental and analysis design
- analytical uncertainty studies

- feasibility experiments,
- demonstration experiments (full scale)
- completion of the experimental program and analysis

The staged approach provides confirmation of methods, periodic assessment of progress and technical findings, and it promotes an opportunity for redesign and redirection during the course of the staged tasks.

1.3 Limitations

The proposed experiments are limited due in part to technical questions and also to avoid process research which might conflict with other current or planned research studies. Primary limitations are:

- The design is oriented toward source/receptor relationships related to sulfur oxides rather than the combination of oxides of sulfur and nitrogen oxides. It is likely that deposition of oxides of nitrogen is controlled by processes over different and more local scales than sulfur dioxide and their analysis would require a significantly different design.

- Lack of suitable reactive tracers limits the ability to develop a design which allows the speciation of sulfur or nitrogen compounds without a significant research effort in processes involved with chemical transformations. The orientation of the proposed plan is to develop source/receptor relationships for total sulfur deposition. Data will be collected in all phases of the experiment which will allow the study of different forms of sulfur oxides but it is possible that conclusions reached in isolating SO_2 and sulfates may not be determined at a known uncertainty level.

- Measurements for determining an empirical source/receptor relationship will take place over a one-year period.

- Losses of material to the free troposphere through cloud venting and other processes will be parameterized from the results of other programs.

- A source/receptor relationship is not directly obtained from the experiments.

- Transferability of the relationships determined by the program to different locations is assumed not proven.

- The model evaluation data base will not be sufficient for a complete evaluation of all individual model components.
- Source characteristics will be calculated rather than being measured.

In spite of limitations and the possibility that the primary objective will not be completely satisfied, the COMPEX experiments will provide an advance in the state of knowledge in acidic deposition. The question of success or lack of success is not black and white. First, the program will generate a data base for model evaluation which will be needed for the new generation of models currently under development. Second, each component of the experiments and subsequent analyses provide a needed improvement in the ability to simulate that component using analytical or empirical models. For example, a priority in COMPEX is the determination of deposition rates representative of areas comparable to the grid spacing of current and future models. Without adequate estimates of deposition over these scales, new models will not be a significant improvement over the old. An additional example comes in commonly asked question about the program, which is, why measured trajectories in an empirical model are an improvement over analytical model calculations. The answer is that the empirical model uses one more verified component (i.e., measured transport and dispersion data) than the analytical model. If the empirical model is not satisfactory in all its components, the experiments still provide the transport information so that the location of deposition can be better estimated.

1.4 Report Organization

The report on the COMPEX design is divided into ten sections with support appendices. In addition, a separate report is available describing uncertainty studies which attempt to resolve some of the feasibility questions raised in this report. Sections which follow are:

Section 2.0 General Approach - a summary section describing the proposed experiments, analysis techniques, and staged experiments.

Section 3.0 Analysis Approach - a detailed look at the characteristics of the measured data and the methods for developing source/receptor relationships from these data.

Section 4.0 Long Range Tracer experiments - sections describing the experimental program.

Section 5.0 Short Range Experiments - sections describing a limited experimental program primarily designed for deposition estimates.

Section 6.0 Routine Monitoring and Support Data Collection - three sections describing the monitoring program and data required from other experimental programs.

Section 7.0 Experimental Management and Control - a section describing the necessary management and coordination of this large experimental program.

Section 8.0 Design Refinements - a discussion of the critical issues in the experimental design and a review of preliminary studies including a description of the role of staged experiments in the design.

Section 9.0 Quality Assurance Program - a description of a quality assurance program.

Section 10.0 Estimated Costs - an estimate of costs for all program components.

SECTION 2

GENERAL APPROACH

This section describes the experimental design in terms of the project objectives and summarizes the individual parts of the design. The analyses leading to development of source/receptor relationships are also discussed.

2.1 Experimental Design

The major objective of the project design is graphically shown in Figure 2-1. This figure represents the overall process relating deposition as a function of space and time to emissions. All deposition (level 4) derives from emissions (level 1) via the intervention of transport and transformation processes. An empirical source/receptor relationship, which is a statistical model, specifies the deposition field attributable to any given source (or the emissions responsible for deposition at any given receptor) without specification of the intervening processes. A physical simulation model would attempt to accurately describe the chemistry and physics of processes and thereby construct a deposition field from a source field. This approach differs from the program objectives of determining empirical source/receptor relationships and providing sufficient information for evaluation of all aspects of process models.

In deriving a source/receptor relationship from measurements, direct path measurements represent processes encountered proceeding from level 1 directly to level 4. Reactive tracer experiments and source modulation experiments are examples direct approaches. Available reactive sulfur isotope tracers are able to mimick the behavior of the most abundant form of sulfur without losing their identity when passing as a primary emission from a specific source to deposition as a secondary form. Three potential sulfur isotopes were identified but two proved to be prohibitively expensive for use in an

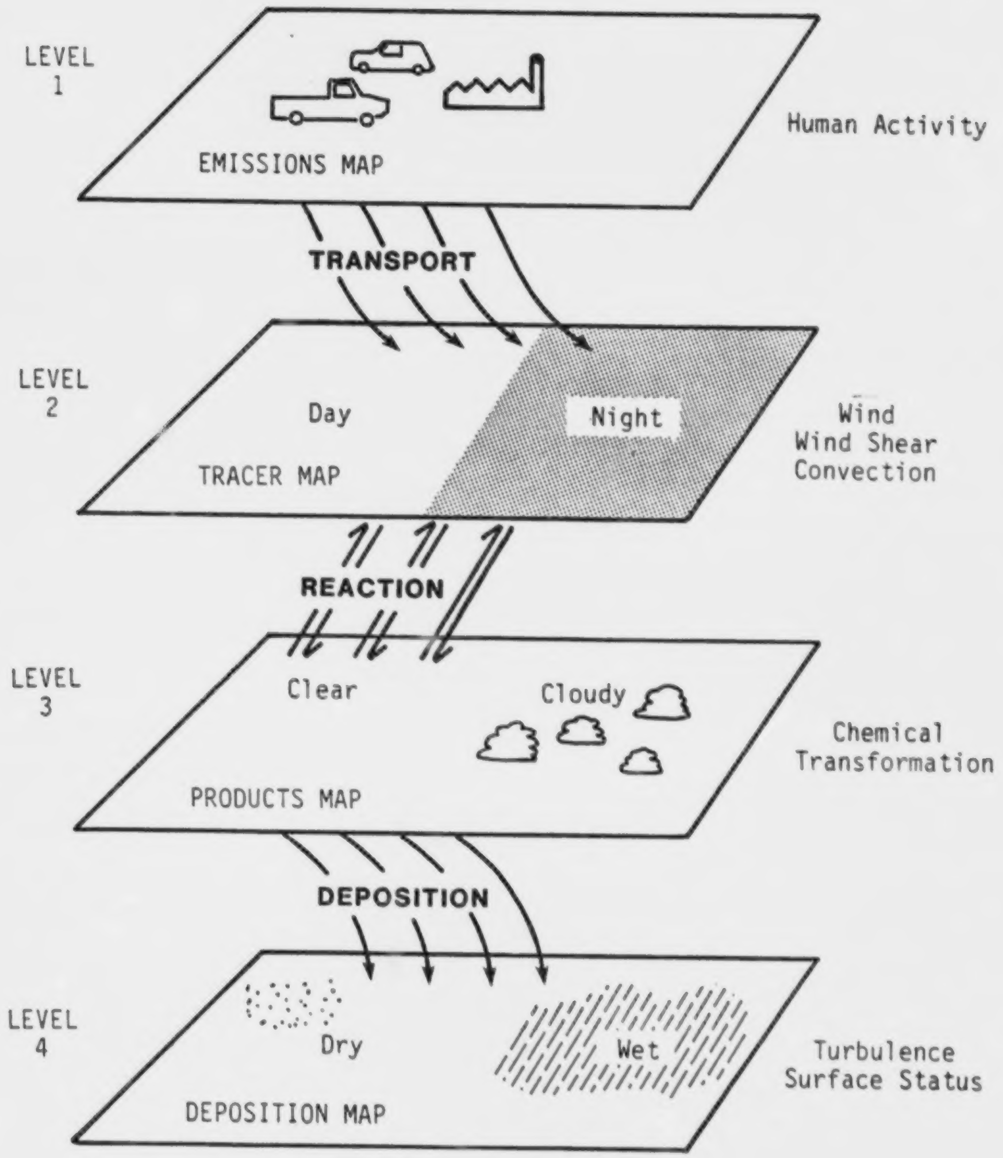
LEVEL 1
EMISSIONS MAP
Human Activity
TRANSPORT
LEVEL 2
Day
Night
TRACER MAP
Wind
Wind Shear
Convection
REACTION
LEVEL 3
Clear
Cloudy
PRODUCTS MAP
Chemical
Transformation
DEPOSITION
LEVEL 4
Dry
Wet
DEPOSITION MAP
Turbulence
Surface Status

Figure 2-1. Design concept - emissions of acid precursors and tracers (Level 1) are transported and diffused (Level 2), undergo chemical reactions and transformations (Level3) and are deposited on the surface (Level 4).

empirical long-range experiment and the third, sulfur-35, is radioactive and unacceptable. The second example, source modulation, is a design by which the effects of changes in sulfur emission levels are directly measured. However, the source modulation required to detect significant effects over a large region of the country is thought to be prohibitively expensive.

An indirect alternative was identified which considers the intermediate levels in Figure 2-1. In the approach, resultant source/receptor relationships are derived from analyses of multiple components statistically or analytically combined. The indirect alternative considered is not process oriented but by necessity makes use of some process studies to tie experimental measurements into complete relationships.

The indirect technique selected is a combined experiment which merges three interactive components:

1. A long range tracer experiment designed primarily to provide estimates of plume transport and dispersion and an estimate of the maximum potential contributions of selected source areas to deposition in the vicinity of a sensitive receptor.
2. Short range studies designed to estimate potential loss of material from emitted plumes over a range of meteorological, chemical, and surface conditions.
3. A fixed station monitoring network which contributes by providing:
   - A framework to describe deposition (comparable to results of previous monitoring programs (e.g., SURE)).
   - A data base for evaluation of models.
   - Qualitative estimates of pollutant transport and fluxes which will be related to conservative tracer measurements.

Figure 2-2 puts the components in the framework of the process description of Figure 2-1. The first component, the conservative tracer experiment, describes pollutant transport and dispersion without depletion. As such, it simulates the maximum potential source contribution to concentrations at a

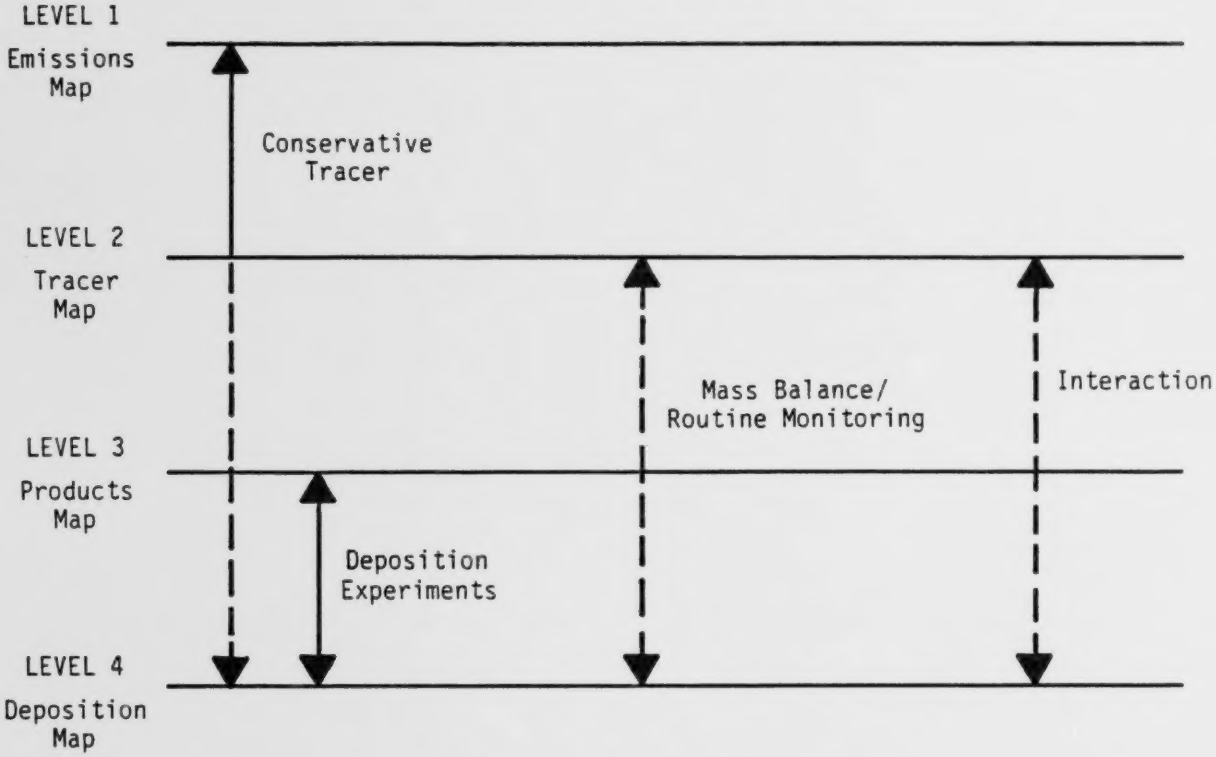
LEVEL 1
Emissions Map
Conservative Tracer
LEVEL 2
Tracer Map
Mass Balance/ Routine Monitoring
Interaction
LEVEL 3
Products Map
Deposition Experiments
LEVEL 4
Deposition Map

Figure 2-2. Use of the data from experimental components to develop source/receptor relationships: direct path (solid arrows and indirect path (dashed).

receptor. In addition, it identifies source areas which do not contribute at a given receptor. Deposition experiments in component 2, the short range deposition experiments, provide information to estimate deposition effects without directly measuring the effects over the 1000 km transport distance. A major deficiency in the current state of knowledge in acid deposition is the lack of information on depsosition over regional scales. This component quantifies the relationships to provide a path from level 3 to level 4 rather than the complete path from emissions to deposition. Routine measurements and the mass balance component provide information which allows a description of the path of materials from level 2, the map of tracers and tagged concentrations, to the chemical products map and eventual deposition. This path description should also be supplemented by ongoing process research studies such as the PRECP* program (Michael, 1984b; see A.5) which is designed to provide information on the non-linear effects of in-cloud processes.

The measurement components described in the following sections were selected to satisfy a transmittance approach with an estimates of plume transport to receptor areas, plume depletion en route, and local deposition rates in receptors areas. The approach takes its name from an estimate of the mass transmitted which is available for deposition at a receptor.

2.2 Characteristics of a Combined Experiment

The combined experiment is a collection of techniques which act as surrogates for the direct experiments. Some of the techniques proposed in the combined experiments represent advanced technology as first time uses the parameterizations and/or combinations of parameterizations, (e.g. in the determination of regionally representative estimates of dry deposition rates.) and the probability of success for these techniques has not yet been proven. This leaves the design with two gross levels of uncertainty to consider. These are, first, the ability to use a composite of techniques to determine an empirical source/receptor relationships and a second determination of whether all the elements of the composite are feasible. To address these concerns, the proposed design is developed with redundant experiments in a progressive or staged approach.

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*Processing of Emissions by Clouds and Precipitation.

Staged experiments refer to phased determinations of the probable success of the program by a combination of uncertainty studies, feasibility experiments, demonstration experiments, and decision points within the main experimental program. Some uncertainty study results are incorporated into this design and are reported in a companion document on uncertainty in regional experiments. Feasibility and demonstration experiments will be conducted prior to the primary experimental year. During the main experiment, partial analyses of collected data will provide an assessment of the success of the complete program and will offer an opportunity for minor modifications.

Redundancy is also built into the program to assure that program success does not hinge on a technique or combination of techniques which is currently unproven. In and among the three experimental components, experimental measurements are proposed which are either duplicates or can be analyzed by an alternative techniques. This repetition provides additional confidence in the design and results while also leaving open the potential for including alternative or innovative techniques in the experiments. The experimental components described are designed to provide data for a mass transmittance analysis, the primary study approach and for development of a data base for model validations. Redundant analysis approaches using modeling and statistical inference will employ the same data base.

The following subsections summarize the major components of the combined experiments. Analysis of the data collected will be discussed in Section 3.0.

2.2.1 Long Range Experiments

The objectives of the long range tracer experiments are to provide measurements for evaluating long range transport and dispersion and in so doing specifying paths for which transmittance calculations will be performed. The experiments will also determine material distributions and transmittances over a limited grid area.

The long range tracer study uses inert tracer releases and sampling to estimate plume dispersion and transport from major source areas within a 1000 km radius of the Adirondacks Region of New York State. This region has been identified as a key receptor area in recent emissions control discussions. Tracer releases during each release period will be made from two source areas using distinct perfluorocarbon tracers. Source areas will have a scale of approximately 100 km and will be represented by multiple release points within the areas (horizontal and vertical). Release rates will be designed to simulate SO_2 emissions distributions in the areas. The locations of source areas will be determined by the locations of major emission sources within approximately 500-1000 km of the primary receptor area. In each release period, the pair of tracer tagged emission source areas will be selected from three possible areas of sectors on the basis of predicted transport directions. In other words, six separate emission areas will be tagged using the tracers but only two will release the material during any one release period. The six sites will be selected from source areas within a 1000 km arc of the Adirondacks. Use of the forecast controlled releases allows a higher frequency of tracer encounters with the receptor area.

The proposed schedule for tracer releases calls for a 24 hour continuous release every third day, with sampling every six hours during the experimental period. The length of releases will avoid biases which could potentially arise from releases in different parts of the diurnal cycle. The three day intervals are intended to provide a large number of samples representing a broad range of meteorological conditions. Cycling of the continuous releases allows a modulation which can be tracked for transport estimates. Transport winds and shear in the winds are expected to segment the 24-hour tracer plumes. This will result in numerous plume elements whose transport will be analyzed to provide a statistical description of plume transport and dispersion particularly in relation to the contribution of specific source areas to deposition at a receptor area.

Sampling for the long range experiment includes measurements of tracers, meteorological parameters, and ambient pollutant concentrations on a nested sampling array. A coarse grid will identify tracer positions and concentrations. A fine grid will provide measurements for flux computations of pollutants in a small receptor oriented area and mass distributions of tracers. Data collected for the flux calculations will include pollutant, precipitation chemistry measurements on a small scale, vertical profiles of wind, pollutants, and tracer, and mixing level.

Sampling from the coarse and fine grid areas will have the resolution of 6 hours for the ground level samplers and approximately 6 minutes for aircraft tracer sampling. Observations will be used in conjunction with chemical and meteorological measurements from the routine monitoring network for the following analyses:

- Mass balance estimates to determine pollutant losses in the receptor area.
- Location of trajectory end points for transmittance approach source attribution estimates.

- Estimation of maximum potential source contributions.
- Estimates of plume transport and dispersion for non-reactive materials.
- Tracer mass distributions used to relate tracer and pollutant concentrations.

2.2.2 Short Range Experiments

The primary objective of the short range experiment is to provide estimates of pollutant deposition which can be used to account for mass depletion in the generalized source/receptor or transmittance relationships. The short range experiments will supplement and may in some ways duplicate the results obtained by the long range tracer and routine monitoring components of the experiments. The three types of experiments considered are:

1. Short range experiments using a reactive tracer (sulfur-34) in ratioed releases with a non-reactive tracer (sulfur hexafluoride).
2. Deposition experiments involving widespread ozone eddy correlation measurements related to deposition of sulfur and nitrogen oxides by measured ratios of measurements of each specie at deposition monitoring sites.
3. Local source modulation experiments.

The first two methods will result in estimates of dry deposition rate or velocity for regional applications while the last will quantify the result of changing emissions of local sources on deposition at a receptor. Methods proposed have been identified as being beneficial on a research basis (Hicks, Weseley, and Durham, 1982), although they have not been fully tested. The authors identify only box budget studies and airborne eddy correlation techniques as potential methods for field experiments in support of large area flux parameterizations.

2.2.3 Routine Monitoring and Support Data Collection

This experimental component will consist of data collection through a network of pollutant samplers deployed in the northeast U.S. and southeast Canada and archiving of data from existing pollutant and meteorological measurement programs. The routine monitoring component will provide the largest data source and is closely associated with the sampling network established for the long range tracer experiments. The support data task will collect data such as routine meteorological data in hard copy and tape form and data from related programs such as the EPA dry deposition network and various precipitation chemistry networks. The data will be used in analyses and for forecasting to control of experimental tracer releases and intensive experiments.

The routine monitoring data will be used in several analysis functions and will provide:

- A data base for regional model evaluation.
- An input data base for models which may be used for real time analysis of data or for program control.
- Input of three dimensional wind fields for trajectory calculations.
- Data for qualitative assessments of the transmittance approach.
- Data for establishing class categories or intervals for analysis.
- A data base for analysis of acid deposition processes.

Monitoring for the study year will include measurements of sulfur oxides and related reactants in air and precipitation. The approach will be an improvement over the SURE, the previous major regional monitoring program in its concurrent measurement of ambient air quality and precipitation chemistry data. It will make the fullest possible use of current related measurement programs (Appendix A). The area of routine monitoring will include the large scale grid proposed for the non-reactive long range tracer experiment.

2.3 Development of Source/Receptor Relationships

Initially, it was felt that a simple, complete, and well behaved relationship could be derived from the experimental data. Such a relationship would be of a form where estimates of deposition from emission sources could be made by multiplying a simple transfer coefficient or function times the emission of each source of interest. The direct approaches described in Section 2.1 were aimed at deriving such relationships; however, the direct approaches appear to be infeasible. This plan provides an indirect transmittance approach where formulations will be developed to describe individual components of acidic deposition processes and these formulations will be combined into a complete source/receptor relationship. The combined experiments were designed to provide data to support this approach. The data collected will also be sufficient to support analysis by modeling and/or statistical inference.

A source/receptor relationship is desired that will allow a determination of source attribution at sensitive receptors resulting from emissions over a long time period (i.e., seasonal or annual). For the purpose of the experiment, a single receptor region is considered from which the contributions of source regions can be determined as shown in Figure 2-3. The transmittance approach has two major components, 1) to determine the amount of pollutant mass in the air over a receptor available for deposition and 2) to estimate the local deposition in the area around a receptor. The approach derives its name from determination of the amount of mass, initially emitted from a source region, that is depleted along the transport route or its converse, the amount of pollutant mass transmitted. The figure shows that the transmittance approach in the combined experiment is a simplification on the relationship between the large array of sources and receptors. In the

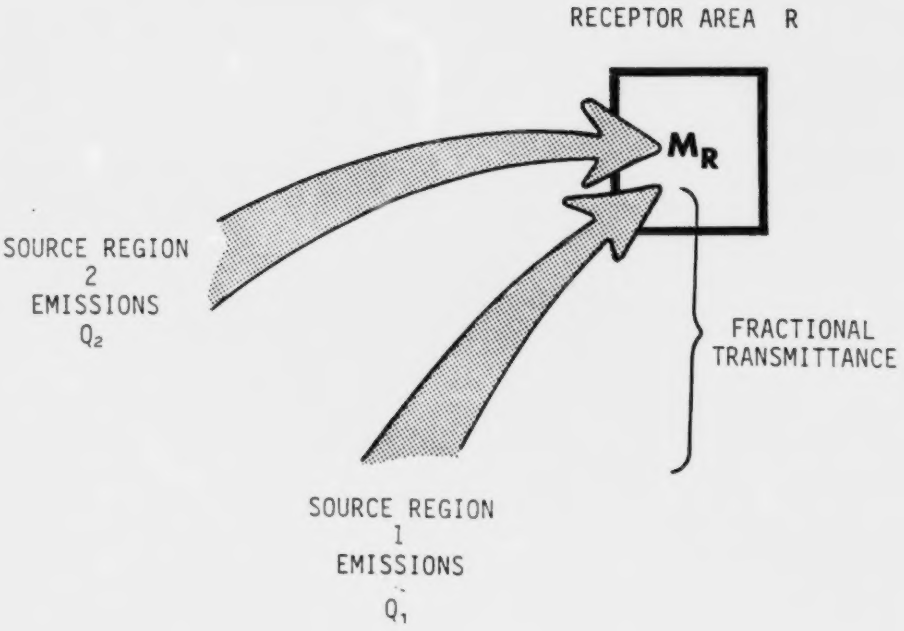
RECEPTOR AREA R
M_R
SOURCE REGION 2 EMISSIONS Q_2
FRACTIONAL TRANSMITTANCE
SOURCE REGION 1 EMISSIONS Q_1

Figure 2-3. Transmittance Approach

experimental design, two or more major emission source regions are tagged by controlled releases of inert tracers during each episode. These will be subject to the long range transport and dispersion. The experiment will also determine if the source areas do not contribute to a receptor area. This experimental data will provide information on the path over which pollutant mass is transported and therefore the path over which transmittances must be specified. The routine monitoring component of the program will provide measurements of actual pollutant concentrations in air and precipitation along this route for use in relating tracer and pollutant concentrations and to provide a check on transmittance estimates.

The mass over the receptor area is not determined by the inert tracer concentration alone. The experimental program will provide detailed three dimensional descriptions of the concentration and meteorological structure of the atmosphere over the receptor area by a combination of ground level, aircraft, and remote measurements. This description will be used in the analysis to estimate losses over the receptor area and the relationship between inert tracer concentrations and the reactive acidic pollutants studied.

The last experimental component is a series of short range experiments primarily designed to determine regional scale depositional losses. The experiments will provide information which can be used as an alternative to measured loss rates in the receptor area but will be more valuable in providing an array of deposition rates as a function of meteorological and surface conditions. This array will be an essential element in calculating fractional transmittances for pollutants along transport paths determined by the inert tracer experiments.

The final analysis of the transmittance approach will empirically define a source/receptor relationship relating pollutant emissions and resultant deposition from individual emission sources. The relationship which forms the basis of the transmittance approach is:

$$D_R^k = \int M_R^k \quad \phi_R \quad dt \tag{2.1}$$

where D_R^k is the time integrated deposition of a pollutant (units: mass/length^2) evaluated at receptor R resulting from emissions at source k. This quantity is determined by integrating, over time, the instantaneous mass per unit area over the receptor, M_R^k, resulting from source k, times the instantaneous deposition rate (units: inverse time) resulting from wet and dry processes, ϕ_R. More simply, it is the remaining mass arriving at a receptor from a source after depletion en route, times the local deposition rate for the receptor. The depleted mass arriving at a receptor will also be determined by field experiments using a trajectory approach to provide parameterizations for a climatological integration of equation 2.1:

$$M_R\ (j) = Q_k \quad P\ (k,\ R;j) \quad F\ (k,\ R;j) \tag{2.2}$$

where the mass resulting from a source is derived from the source strength for pollutants emitted at source Q_i. P is an impact factor for an inert tracer release as a function of meteorological conditions j between the source and the receptor R. F is the fractional transmittance which relates the tracer impact to a pollutant impact by defining the potential depletion of mass en route from source k to the receptor R for meteorological conditions j. The fractional transmittances are given by the path integrals along trajectories from the sources to the receptor:

$$F = 1 - \int \phi v^{-1} ds \qquad (2.3)$$

where ϕ is the fractional removal rate per unit time, v is a representative transport velocity, and ds is the length of a path element. The determination of deposition rates is both the most important and uncertain component of the experiments. As such, three distinct methods have been proposed to estimate deposition as a consistency and precision check and provide backup results for periods when one technique may not be optimum for the conditions encountered.

SECTION 3

ANALYSIS APPROACH

The primary analysis technique for the COMPEX design is a transmittance approach. The experimental program is designed to fill the data needs for this analysis while providing a data base for model evaluation. Alternative analysis approaches, namely, modeling and statistical analyses, are identified as redundant methods which can be used with data from the combined experiment. This section describes analysis approaches by first considering the concepts behind the transmittance approach and the characteristics of this data set available from the combined experiments. Additional subsections then describe the components of the transmittance, modeling and statistical analysis approaches.

3.1 General Analysis Approach

The combined experiment concept is that a collection of experiments can be assembled which have a high probability of providing sufficient data to develop source/receptor relationships. The derived relationships will be an improvement over source attribution techniques currently in use, and measurements will suffice to determine the uncertainties involved in their development. Since the experiments are a combination of complex elements, the resultant levels of uncertainty cannot now be estimated without additional information from pilot studies. Until such studies are performed, it cannot be stated with certainty that the experiments will provide relationships with acceptable uncertainty limits.

The component of the combined experiment which can be performed with the highest degree of confidence is the first component, the long range tracer experiments. They provide information on transport and dispersion of pollutants in the absence of plume depletion. These techniques have been proven in previous experiments (e.g., CAPTEX)*. The weakest link in developing source/receptor relationships is using the conservative long range tracer information with independent estimates of plume depletion from the second component for transmittance estimates. To overcome some of the uncertainty in this component, the combined experiment estimates plume depletion using four independent methods:

- Mass balance measurements associated with long range tracer experiments
- Local source modulation
- A local reactive tracer study (sulfur-34)
- A combined technique of aircraft eddy correlation measurements and determination of interspecies deposition ratios

The third element of the combined experiment is a routine monitoring program which will provide data to characterize the chemistry and meteorology of acidic deposition processes, support long range tracer experiments, and provide data for model evaluation.

3.1.1 Approach to Meeting Analysis Objectives

The primary objective of the comprehensive field study is to design an experiment capable of directly providing a series of empirical source-receptor relations at a known level of uncertainty. The concept of the design as illustrated in Figures 2-1 and 2-2 consists if four levels of activity leading to the desired result. Level 1 represents the emissions of primary acidic pollutants, or precursors. Level 2 represents the map of tracer concentrations, the product of pollutant transport. Level 3 represents the chemical reactions and transformations that may take place in clear or cloudy air to relate ambient concentrations of pollutants and tracers. All of these contribute to level 4 which is the deposition map.

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*Cross-Appalachian Tracer Experiment

Figure 2-2 provides additional description of the transmittance approach. The long range tracer experiment represents the processes between level 1 to level 2. The reactive tracer experiment and other short range experiments are designed to provide information on deposition (from level 3 to level 4). The mass balance and routine monitoring studies provide data to connect the tracer map (level 2) to the deposition map (level 4). In summary, the approach is to develop transmittance or incremental transfer functions which combine empirical and process oriented analyses to derive relationships reflecting the influence of meteorological and source variations on wet and dry deposition. Table 3-1 lists the generic measurements to be available for analysis, the basic type of analysis to be performed, the use of the data, and the tie to source/receptor relationship.

The first step in the analysis involves use of ground level concentration patterns portrayed in time sequences along with meteorological measurements to develop air parcel trajectories from tracer source regions. The path of the air parcel affecting the receptor region is identified, and the potentially contributing source areas are identified. Tracer concentrations in the receptor region are used to establish maximum potential influence of the source area on a receptor.

The second step is to establish the deposition rates, both wet and dry, from air parcels as they traverse the receptor region. Trajectories and source contributions are currently measureable, but amount of material loss along the path of tracer to deposition or transformation process is uncertain. Short range experiments are described which will attempt to determine deposition rates. These rates will be applied along the trajectory of the air parcel in conjunction with the tracer measurements to apportion source impact.

TABLE 3-1
USES OF MEASURED DATA FOR THE TRANSMITTANCE ANALYSIS

Measurements	Analysis	Use of Data	Tie to Source/Receptor Relationship
1. Emission rates	Area and time history	1 +2 Relative concentration at receptor for tracer	Maximum source influence for a specific (inert tracer emitting) area
2. Receptor concentrations at ground level of SO_2, O_3, NO_2, tracer profiles	Ground level concentration patterns	2 +3 +5 Flux at faces of receptor region	Loss of material to deposition, or transformation across region
3. Aircraft observation at 2 or 3 heights	Cross-face distribution	1 +2 +3 +5 +6 +7a,b Dry deposition	Dry deposition attributed on basis of air parcel trajectory and estimated deposition
4. Receptor observation of wet deposition and other anions NH_4^+, H^+ other cations $SO_4^=$, NO_3^-	Ground level wet deposition patterns	1 +2 +3 +4 +5 +6 Wet deposition	Wet deposition attributed on basis of air parcel trajectory
5. Rawinsonde: Wind, temp., humidity	Wind, temp., humidity patterns with height		Mass balance through receptor region attributed on basis of above to establish source/receptor relationship
6. Surface meteorological observations	Pressure, wind, temp., humidity patterns		
7. Short range deposition experiments			
a. Emission rates $^{34}SO_2$ Tracer 1, Tracer 2	Time history	7a,b Deposition velocity as f(c, surface, meteorology)	Establishes parameterization of dry deposition losses as function of concentration, surface character, and meteorology
b. Ground-level concentration measurements 50 locations $^{34}SO_2$, Tracer 1, Tracer 2	Ground-level concentration patterns. Cross-wind integrated concentrations. Ratios		
c. Eddy correlation technique and ratios of O_3, SO_x, NO_x	Flux of O_3 from aircraft measurement	7c Deposition velocity of S, N	
d. Local source modulation	Deposition changes in affected area	7d Direct measure of changes in deposition	Establishes direct measure of local source on deposition in receptor region

3.1.2 Experimental and Analysis Redundancy

The design includes redundant elements as an acknowledgement that the transmittance approach, like other indirect approaches, may have limitations due to measurement technology and meteorological variability which could prevent the complete fulfillment of the objectives. It also provides an opportunity for substitution of more advanced techniques as they become available. The first level of redundancy is provided by the objectives which require a program designed for two purposes where the objective of developing source/receptor relationships is considered primary. The second level of redundancy is in the approaches or paths as shown in Figure 3-1. The primary method of satisfying the objective of source attribution is through a transmittance approach. The analysis of the program data will also take two additional forms, modeling and statistical inference. The third level of redundancy is the individual tasks under each approach. The objective of the third level is to avoid potential failure of the program on the basis of an individual weakness in a task.

3.2 Characteristics of the Data Set

Measurements made during the combined experiment can be considered routine or intensive. Routine includes all of the measurements of meteorological, and air and precipitation chemistry parameters on the coarse and fine mesh grids. Intensive measurements include experiments for depletion estimates including aircraft measurements. Table 3-2 describes the parameters collected in each experimental component in terms of temporal and spatial resolution and numbers of sites.

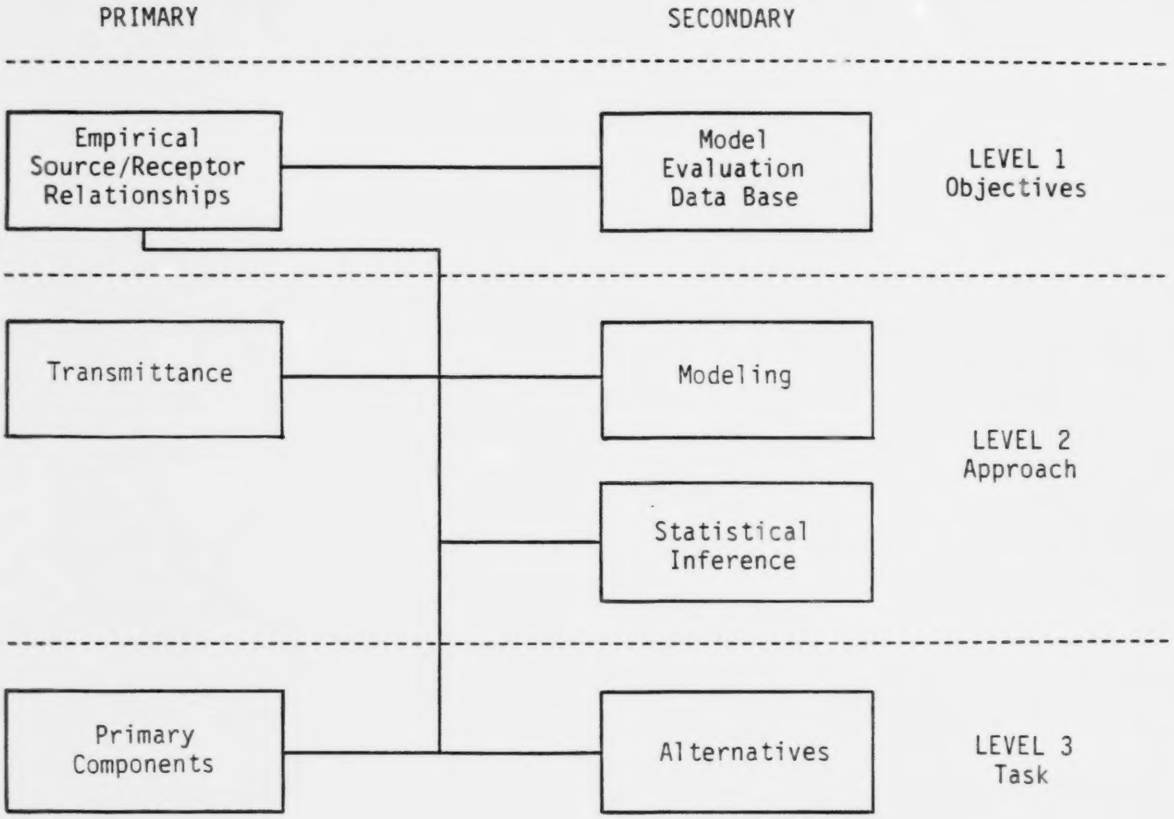
PRIMARY
SECONDARY
Empirical Source/Receptor Relationships
Model Evaluation Data Base
LEVEL 1 Objectives
Transmittance
Modeling
Statistical Inference
LEVEL 2 Approach
Primary Components
Alternatives
LEVEL 3 Task

Figure 3-1. Redundancy in the COMPEX design.

TABLE 3-2
CHARACTERISTICS OF DATA

Experimental Component/Data Type	Parameters	Data Collection Averaging Period/ Frequency	Approximate Number of Sites	Grid Resolution	Notes
Coarse Grid					
Air Concentrations	2-PFC's, SO_2/SO_4, NO_3/HNO_3	6 hr intervals	100	100-130 km irregular	
Precipitation	Totals	Event	100	100-130 km irregular	
Precipitation Chemistry	Major ions	Event	100	100-130 km irregular	
Rawinsonde	Wind speed/ direction T, Td Profiles	4 per day	22	irregular	See Figure 6-1
Release Information					
Doppler Acoustic Winds	Ws/wd at release height	Continuous	6	-	One site in each release area
Fine Grid					
Rawinsonde	Ws/wd, T, Td profiles	3 hr intervals	4	200km	Measurements during mass balance measurements
Air Concentrations	2 PFC's, SO_2/SO_4, NO_3/HNO_3	6 hr intervals	57	20-100 km	
Precipitation Chemistry	Major ions	Event	57	20-100 km	
Aircraft Concentrations	SO_2, SO_4, NO_3, HNO_3, 2-PFC's	30 min. intervals each flight 6-10 min. intervals each flight	3 Aircraft	-	3 levels/parameter on 240 km square. 2 flights per experiment,
Lidar wind and Concentration measurements	wind components O_3, SO_2, Mixing Height	minutes	5	100 km	

TABLE 3-2
(Continued)
CHARACTERISTICS OF DATA

Experimental Component/Data Type	Parameters	Data Collection Averaging Period/ Frequency	Approximate Number of Sites	Grid Resolution	Notes
Local Source Modulation					
Reactive Tracer Concentrations	$^{34}SO_2$, SO_4, SO_2, Freon, SF_6	Intensive	50	0.5-2km Local studies	Uses fine grid measurements, resolution set by individual experiment
Eddy Correlation Study					
Ground Measurements Fluxes and Concentrations	O_3, SO_2, NO_x	Continuous in intensive periods	2	Point Measurements	
Aircraft	O_3, Fluxes, SO_2, O_3 eddy Correlations	Continuous intense periods	Aircraft	Perimeters 10-20km sides	
Supplementary Data					
Tracer Emissions	2 Tracers	Hourly	2	-	Three potential sites per tracer
Synoptic Meteorology	Pressure, T, Td, ws, wd, clouds, precipitation	Hourly	150	80 km	
Pollutant Emissions	SO_2, NO_x HC	Hourly in traced area - short term allocation	-	80 km	Major source information also required

3.3 Transmittance Approach

The following subsections describe the general concept involved with the transmittance approach.

3.3.1 General Equations for Transmittance

The objective of the analysis is to determine source attribution on an empirical basis representing long term (i.e. seasonal or annual) conditions. The combined experiment provides data to derive these relationships by analyzing a collection of deposition events which occur in a one year period. The primary approach selected is a transmittance technique illustrated in Figure 2-3. In the figure, two source areas southwest of a receptor area are shown to potentially influence the receptor during a given meteorological condition. Potential influence is indicated by detection of an inert tracer from the source area at the receptor area. A determination of whether the potential influence is realized is made by examining losses of pollutants en route (i.e., on the trajectory) from the emission source to the receptor. Some fraction of the mass transmitted is deposited locally in the receptor area. This portion when given as the fraction of total deposition, defines the source contribution for some short-term period. Results of a number of episodes is combined in a relationship to represent the long term contribution of the individual source area. It is assumed that the relationships developed in one area can be used to represent the acid deposition processes occuring in other areas. The program plan identifies up to six tracer release sites in various locations which will be sufficient to analyze this assumption.

The relationship used to express the transmittance approach is summarized conceptually in the following equations:

$$D_R^k = \int M_R^k \quad \phi_R \quad dt \tag{3.1}$$

where D_R^k is the time integrated deposition of a pollutant (units: mass/length^2) evaluated at receptor R resulting from emissions at source k. M_R^K is the pollutant mass transported between the source and receptor and ϕ_R is the local deposition rate (units: inverse time). The time integration collects deposition events to provide a long-term expression for deposition which is the desired source/receptor relationship. The integral is evaluated by replacing Equation 3.1 with a summation over the expected meteorological conditions during the study year:

$$D_R^k = \sum_j f_j \quad M_R^k \ (j) \ \ \phi_R \ (j) \qquad (3.2)$$

The expression relates the climatological frequencies of transmitted mass and local deposition conditions with a frequency f_j. The mass arriving at a receptor area M_R^K is a function meteorological condition j at the receptor and also represents some combination of meteorological conditions en route between source and receptor.

A climatological data base is required to adequately describe deposition using this expression. A one year data collection period is proposed as a compromise between a long term record and cost. It is accepted that this proposed experimental method comprised of one years record may not be representative of other years. However, the cost of obtaining longer, more representative records is not practical. A one year period will permit study of the process in a variety of seasons. Careful analyses of the meteorological conditions during the study year will be required to determine if the resultant relationships are climatologically representative.

Values for the terms in equation 3.2 are provided by the experimental components. Under the combined experiment design, the deposition rates will be parameterized based on short range field experiments for wet and dry deposition. The total deposition rate is given as a sum of wet and dry rates:

$$\phi_R \ (j) \quad = \phi_R \ (j)_{wet} \ + \ \phi_R \ (j)_{dry} \qquad (3.3)$$

The transmitted mass arriving at a receptor will also be determined by field experiments using trajectory and concentration data. The pollutant mass contributed by a source area is given by:

$$M_R^K\ (j) = Q_k\ P\ (k, R;j)\ F\ (k, R;j) \tag{3.4}$$

where Q_k is the pollutant emission rate for source areas being simulated. The parameter P is defined as an impact factor for an inert tracer. This factor is represents how much the initial tracer volume has expanded by dispersion in terms of mass per unit volume of emissions. Experimentally, the impact factor is derived from the measurement of tracer concentration in the receptor area. The importance of this term is reflected in high resolution measurements proprosed for the description of the mass distribution over the receptor area.

To obtain an estimate of deposition for a reactive pollutant, a determination must be made of the fractional transmittance of pollutant F. Fractional transmittances in essence describe the relationship between tracer and pollutant concentrations. These are given by the path integrals along trajectories from the sources to the receptor:

$$F = 1 - \int \phi\ v^{-1} ds \tag{3.5}$$

where ϕ is the fractional removal rate per unit time, v is a representative transport velocity, and ds is the length of a path element. The deposition rates for both the local deposition and the loss of material en route are of the same form and are determined primarily by short range experiments.

Experimental requirements under the transmittance approach outlined above can be summarized as follows:

- Transport paths of polluted air parcels from specific sources at a specific receptors - These are the integration paths required to estimate fractional transmittances and are determined by long range tracer releases and measurements.

- Impact factors showing the effects of transport and dispersion on emitted pollutants - Impact factors are found by careful measurements of inert tracer concentrations on a fine mesh grid in the area.

- Deposition rates - Deposition rates will be required both in the determination of local deposition and fractional transmittances. Deposition rates will be determined locally in the receptor area by flux differences in conjunction with routine monitoring data. Additional estimates of deposition rate will be made in the short range experiment component of the combined experiment.

- Climatological data - The routine monitoring task specifies procedures for collection of climatological data.

The following subsections provide additional detail on the analyses required in this approach.

3.3.2 Long Range Tracer Experiments - Transport and Mass Balances

The long range tracer program consists of large scale tracer releases and measurements in conjunction with high resolution measurements in the vicinity of a sensitive receptor region. The main objectives of the long range tracer program are to determine pollutant (tracer) transport in the atmosphere, to describe the distribution of tracer mass in the vicinity of the receptor, to estimate deposition and transmittances by a mass balance approach, and to estimate tracer impact factors.

Transport and Dispersion

The tracer releases sampled on the coarse monitoring grid, in combination with meteorological measurements, provide definite transport path from each source region. These data will be used both to calculate empirical transport statistics for individual receptors to test the transport formulations in acid deposition models.

Individual trajectory statistics will be developed at each of the tracer release points. Trajectories will be based on the observed wind fields and the spatial of tracer concentration patterns. Trajectory paths will be calculated from the occurrence of tracer plume elements at individual sampling sites. Difficulties in establishing trajectories of individual parcels may be encountered during stagnation or high wind shear conditions, but overall air parcel trajectories will be established by the time sequences of tracer measurements. This method appears to be adequate based on CAPTEX ground level tracer concentration data.

The data generated in this analysis will provide measures of trajectories which may be used directly in the validation of trajectory and dispersion modules of acid deposition models. They will also provide integration paths for the transmittance approach. Analyses of trajectories measured under a variety of situations have indicated that the model calculated trajectories have a root-mean-square-error approximately equal to half of the distance of travel (Pack et al., 1978). A program component will be ongoing comparisons of trajectories from models with tracer derived values.

The distribution of trajectories provides a measure of the amount of time that the identified source area affects a specific receptor region. The tracer concentrations provide a measure of the relative dispersion from the various source areas. The relative dispersion provides an upper limit on the amount of material carried in the air mass as it is transported to the receptor region. It also provides an estimate of the impact factor needed in the transmittance relationships.

The redundant technique for determining air parcel trajectories will be calculations based on either objectively analyzed or dynamic forecast model output wind fields. Calculations are possible with using constant level, layer-averaged or isentropic trajectory calculation schemes.

Transmittance and Flux

The fine mesh grid in the Adirondacks region will serve as the target for transmittance calculations. The area will be the site of a sophisticated monitoring network designed to describe transport, deposition and dispersion using an array of interrelated measurements. In the area, ground level measurements of air and precipitation chemistry will be supplemented with data including remotely sensed profiles of wind and concentrations and rawinsonde winds. In addition, aircraft measurements will be made to facilitate mass flux estimates.

Measurements on the grid will serve the following purposes:

- Detailed, three dimensional tracer concentration fields from surface and aircraft sampling will be used to provide tracer impact factor estimates.
- Differential Absorption Lidar (DIAL) and aircraft concentration data will be used to provide details of vertical concentration profiles for different meteorological conditions.
- Lidar data will be used to guide the selection of heights for aircraft sampling.
- Dial measurements in combination with lidar wind profile data will be used to give spatial distributions of fluxes for SO_2, ozone, and relative particle concentrations.
- Tetroons will serve as Lagrangian markers for air masses during mass flux experiments.
- A combination of all grid measurments for pollutants and tracers will be used to estimate fluxes of tracers and pollutants from which deposition estimates will be made.
- Weather radar, precipitation, and precipitation chemistry data will be used to estimate pollutant losses by wet deposition.

Fluxes into and out of the receptor region will be calculated from the concentrations, deposition rates and wind profiles developed by the measurements program. Surface concentrations and deposition measurements from the small scale intensive programs must be coordinated with the measurements of concentrations made aloft and on the larger scale. This will facilitate estimates of fluxes of material through upwind and downwind sides of the receptor region. Flux measurments assume non-divergent steady-state conditions. These assumptions will be checked for each measurment episode.

It is recognized that aircraft sampling will not yield average concentrations which may be used for the calculation of flux in the normal manner. It is only through repeating the experiments for the receptor region on an essentially continuous basis and supplementing the data with remotely sensed wind, that concentration and flux profiles plus average values and variability can be calculated. Assuming that there is correspondence between the values aloft and those measured at the ground, some measure of time variability can be obtained from the surface sampling network. Conditions under which this correspondence fails will be identified in the analysis.

Equation 3.6 is a generalized representation of the calculation of mass balance.

$$\underset{\text{measured}}{\begin{bmatrix}\text{Flux}\\\text{In}\end{bmatrix}} + \underset{\text{"known"}}{\begin{bmatrix}\text{Emissions}\\\text{Within}\\\text{Receptor}\\\text{Region}\end{bmatrix}} = \underset{\text{measured}}{\begin{bmatrix}\text{Wet}\\\text{Deposition}\end{bmatrix}} + \underset{\substack{\text{estimate}\\\text{from}\\\text{experiment}}}{\begin{bmatrix}\text{Dry}\\\text{Deposition}\end{bmatrix}} + \underset{\text{measured}}{\begin{bmatrix}\text{Flux}\\\text{Out}\end{bmatrix}} + \underset{\substack{\text{effect}\\\text{included}\\\text{in}\\\text{measured}\\\text{flux}}}{\begin{bmatrix}\text{Loss}\\\text{Due to}\\\text{Chemical}\\\text{Conversion}\end{bmatrix}} \quad (3.6)$$

Flux in and out are measured quantities described previously. The emissions within the receptor region are expected to be small but known. The receptor region was selected specifically to be remote from any major sources. Wet deposition, is measured throughout the receptor region, and total wet deposition is analyzed with the aid of radar data. Dry deposition will be estimated from using the short range reactive tracer experiments or other techniques (Section 3.3.3). The design of this experiment does not include an analysis of the loss due to chemical conversion or transformation. It is anticipated that other programs which are process oriented will provide information with which this chemical conversion may be estimated during the course of the experimental program. Experience in previous experiments such as AMBIENS (Shannon and Hicks, 1977) suggest that estimation of the deposition of specific species is not possible unless chemical conversion rates are known.

The mass budget technique will be used primarily to estimate deposition velocity. While simple in concept, it is somewhat difficult to implement. The horizontal flux of a depositing material measured at some distance, x, downwind of a source is given by Horst et al. (1983) as:

$$\overline{UC}_d^{y'z'}(x) = \int_0^\infty \int_{-\infty}^\infty u(z')\, C_d(x, y', z')\, dy',\, dz' \qquad (3.7)$$

Here u is the mean wind speed, and C_d is the airborne concentration of the depositing tracer. The overbar notation represents the integral over the cross-wind y', and vertical z', coordinates. The total deposition rate between the source and distance x is found by subtracting this horizontal flux from the release rate Q_d. The total deposition rate determined in this manner is then equal to the upwind and cross-wind integral of the local deposition rate, parameterized as a deposition velocity v_d multiplied by the airborne concentration measured at height z_d.

$$Q_d - \overline{uC}_d^{yz}\ (x) = v_d \int_0^X \bar{C}_d^{y}(x', z_d)\, dx' \qquad (3.8)$$

Equation (3.8) can be solved for deposition velocity, and v_d is determined from observation of C_d, Q_d and u.

Horst et al. (1983) described some of the difficulties that are expected in measuring the left hand side of equation (3.8). If the deposition is a small fraction of the release rate, then all terms must be measured very accurately. Precise vertical measurements to the top of the dispersing cloud are required as well. Another area of concern is the flux measurement itself. Flux is defined as the average of transport times concentration or:

$$\text{Flux} = \overline{uC} \qquad (3.9)$$

but the average flux is usually determined from the average values of each term and their covariance, i.e.:

$$\overline{uC} = \bar{u}\,\bar{C} + \overline{u'C'} \qquad (3.10)$$

(Priestley; 1959). The covariance term is difficult to measure and frequently is assumed to be 0 for horizontal transport.

Therefore, the mass balance effort depends on accurate measures with adequate time resolution for the period being studied. The analysis must take into account the uncertainty of the measurements and check the assumption of negligible covariances.

Equation 3.11 is a general representation of the transmittance function determined across the receptor region.

$$\text{Flux Out} = T_{FR} \times \text{Flux In} \tag{3.11}$$

$$T = f\,(\text{meteorology, surface conditions})$$

Flux out is equal to the transmittance function for the receptor area, (T_{FR} or some ΔF) times the flux of material in for species under consideration. The transmittance factor is a function of meteorology and surface conditions. Transmittance factors developed from fine scale measurements, will be analyzed with those derived from other deposition rates and applied to trajectories defined by the tracer. Meteorological conditions will be identified for categories related to air mass characteristics, transport paths across the region, precipitation amount, and type of precipitation.

3.3.3 Short Range Experiments - Dry Deposition

Wet and dry deposition estimates are required in the calculation of fractional transmittances. The need for such experiments has been determined by the dearth of data applicable to depositional losses on a regional scale. Numerous experimental techniques are presented for estimation of dry deposition rates. Measurements will be made to provide deposition estimates by 1) flux difference method (long range tracer experiments), 2) ozone eddy correlation/ratio techniques (short-range experiments) 3) reactive tracers, 4) use of currently available deposition velocities composited to regional scale by a review of land use data. The analysis methods used for dry deposition estimates are as follows:

Flux Difference

The approaches described in the previous sections on mass transmittance are used to define a deposition rate. An expression for deposition rate can also be given by the following relationship:

$$\phi = \frac{\iint C \; v \; dy \; dz \big|_{in} - \iint C \; v \; dy \; dz \big|_{out}}{\iiint C \; dx \; dy \; dz} \qquad (3.12)$$

In the equation, the difference in fluxes in and out of a volume are normalized by the integral of mass in the volume. Some restrictive assumptions are required, namely that the flow generating the fluxes is non-divergent and steady and that the loss of material represented is the result of deposition rather than chemical transformation.

Eddy Correlation/Concentration Ratio

One of the techniques that will be used to determine deposition rate on a regional scale will be a new method which combines aircraft measurements of ozone flux with comparisons among other pollutant fluxes near the surface. The method of measuring ozone fluxes by aircraft and a comparison of data to eddy correlation measurements was described by Lenschow et al., (1980). The technique generates ozone flux estimates by the eddy correlation relationship:

$$\text{Flux} = \overline{w'C'} \qquad (3.13)$$

where the parameters are fluctuations of vertical velocity and concentration obtained from fast response instrumentation. Signal processing by this equation and a calibration based on tower data resulted in reliable flux estimates.

The lack of fast response instrumentation for sulfur and nitrogen oxides precludes the use of the Equation 3.13 and similar measurments in estimating fluxes. To overcome this deficiency, the experiment will determine pollutant fluxes based on the ozone fluxes measured by the aircraft in a relationship with sulfur and nitrogen oxide concentrations and the ratios of flux estimates of these compounds and ozone determined at a tower site.

Analyses will include processing to determine the ozone fluxes and estimates of other fluxes using a relationship with dependent parameters including the ozone flux, the ratios of fluxes based on the tower measurements, aircraft concentration measurements, and meteorological variables. An additional calculation will be used to estimate deposition velocities and rates.

Reactive Tracer Experiments

A sulfur-34 experiment will measure deposition of sulfur dioxide by comparison to non-depositing tracers. Horst (1977) described the surface depletion method for deposition which is applicable to this experiment. The model represents deposition at location (x', y') as a negative, ground level source, with a source strength per unit surface area equal to the deposition flux $v_d\ C_d(x',\ y',\ z_d)$. The depletion of the airborne concentration at location (x,y,z) caused by deposition at the upwind location (x',y',z = 0) and the diffusion of that loss (deposition of material) over the distance (x-x', y-y',z). The total depletion at (x,y,z) is then found by integrating over all deposition upwind of x.

$$C_o(x,y,z,h)-C_d(x,y,z,h)=\int_{-\infty}^{\infty}\int_{0}^{x} v_d C_d(x',y',z_d,h)D\ (x-x',y-y',z,h=0)\ dx'dy' \tag{3.14}$$

where h is the source height of the depositing tracer and the diffusion of the material loss is denoted by the function D. D is determined from an inert tracer released at ground level, i.e.,

$$D\ (x,y,z,h = 0) = \frac{C_o(x,y,z,h = 0)}{Q_o} \qquad (3.15)$$

Substituting (3.15) into (3.14) and cross-wind integrating the equation, Horst et al. (1983) obtained a method to evaluate depletion at sampler height $z = z_d$, using

$$(Q_d/Q_o)_h \left[C_o^y\ (\bar{x}, z_d, h) - C_d^y\ (x, z_d, h) \right] =$$

$$v_d \int_0^x \bar{C}_d^y\ (x, z_d, h)\ \frac{1}{Q_o}\ \bar{C}_0^y(x-x', z_d, h = 0)\ dx' \qquad (3.16)$$

This method has the major advantage that only ground level (sampler height) concentration is required. The left hand side of equation (3.16) can be measured with reasonable accuracy, ± 15 percent for concentration and ± 5 percent for source rate according to Smith et al. (1983). However, concentration patterns must be measured from the source through the receptor region to permit the appropriate downwind integration.

Two inert tracers were required as noted in the design. An inert release $(Q_o)_h$ at height h in combination with the reactive or depositing tracer (Q_d) is required to measure the depletion at distance x (left hand side of equation (3.16)). The ground level release of an inert tracer (Q_o) is used to determine the diffusion of negative sources (deposition loss) (right hand side of equation 3.16).

Concentrations of all three gases are available from the sampling grid. Cross-wind integrated concentrations will average and smooth out some of the measurement error. If the level of errors is not reduced, differences between the depositing and non-depositing tracers will need to be large, perhaps in excess of 40 percent. Pilot studies are required to estimate expected uncertainties from this method.

Another analysis technique uses ratios of isotopic sulfur tracers to inert tracers from the same experiment to determine the rate of removal. Specifically the technique compares concentration ratios between measurement points along a transport path on the measurement grid by:

$$\phi = \frac{v}{x} \left\{ \left[\frac{\int C_d \; dz}{\int C_o \; dz} \right]_{\text{upwind}} - \left[\frac{\int C_d \; dz}{\int C_o \; dz} \right]_{\text{downwind}} \right\} \qquad (3.17)$$

where the ratios are for vertically integrated concentrations of the isotopic depositing tracer C_d and the inert tracer C_o. The measurements indicate the depositional losses over a time represented by the separation distance of the measurements, x, and the transport velocity, v.

Use of the ratio technique is subject to difficulties in three areas, the definition of a transport velocity, the determination of concentration profiles for integration, and the expected differences in ratios relative to measurement uncertainty at the travel distances proposed (i.e., 20-50 km). In practice, the technique may require modification to overcome difficulties with the transport layer and vertical profiles. Results of preliminary uncertainty analyses (Section 8.3) indicate that the most significant problem is the detectability of the ratio differences. Analytical studies suggest that measurement uncertainties may far exceed deposition losses. The conclusion should be confirmed prior to use of the technique in the experimental program.

Deposition Velocities

Dry deposition rates can be determined from deposition velocities determined in other experimental programs. This approach is currently being used to estimate dry deposition from concentration network data in Canada and the U.S. The difficulty with this approach is that measured deposition velocities are generally not of a scale representative of regional areas. Experimental constraints of uniform fetch for various measurement techniques generally results in estimates of deposition for restricted land form and surface conditions. On a regional scale, surfaces appear to pollutants being transported in a region as composites or mosaics of different surface types. For the purposes of this experiment, use of existing deposition velocities will serve as an alternative approach. It will include an analysis of deposition losses by weighted averaging of deposition velocities in an area or by reducing transport path intervals to sizes more local in scale prior to use in transmittance calculations. Weighting for the averaging analysis will be related to the area of uniform surface type in a particular region.

Deposition rate used in the transmittance approach will be determined from deposition velocity (v_d) by the following relationship:

$$\phi = v_d H^{-1}$$

where H is a characteristic height given by:

$$H = \frac{\int C \, dz}{C(z_{ref})} \qquad (3.18)$$

This relates the vertically integrated concentration to that of a reference height z_{ref}. The required vertical concentration profile is a difficult parameter to obtain and may need to be calculated with a parameterization from the mass balance component of the study. In this component, concentration profiles will be available from lidar and aircraft measurements. It may be possible using this data and SURE aircraft data to determine a concentration parameterization based on meteorological parameters and surface level concentrations.

3.3.4 Short Range Experiments - Wet Deposition

Wet deposition estimates will be derived from precipitation chemistry data collected on the fine resolution receptor grid. The data will be used to provide an expression for the wet component of the deposition rate. From th event data, the deposition rate will be given by the following expression:

$$\phi_{wet} = \frac{C_R\ r}{\int C_a\ dz} \qquad (3.19)$$

where ϕ_{wet} is the rate of wet deposition (units: inverse time) which results from dividing the concentration of pollutant in precipitation by the precipitation rate, r. This results in a flux of pollutant in precipitation. This numerator is divided by the intergal of pollutant mass in the air column above the precipitation monitoring site. This expression is similar in form to a washout ratio which gives the ratio of the concentrations of pollutants in air and precipitation.

The analysis of the wet deposition data is difficult because, like precipitation data, the wet deposition of pollutants by event is highly variable and determination of the vertical concentration integral is difficult. The spatial analysis of the experimental data must represent a real deposition totals. One technique is the use of a fine grid precipitation network although the grid may be insufficient for sampling precipitation during some events (i.e., during some convective precipitation events).

Concentration data for pollutants in precipitation be supplemented with digital radar precipitation data to provide a better estimate of the area of the fine mesh grid covered by precipitation.

Spatial analyses of the acid precipitation data to integrate total deposition over the receptor area may utilize methods such as Kriging interpolation to minimize interpolation error (e.g., Finkelstein, 1984; Bilonick, 1983; Bilonick and Nichols, 1983).

The vertical concentration integral is likewise difficult to estimate. Concentration profiles, in the SURE data base, are highly variable particularly at lower levels. Measurements of sulfur oxides profiles are possible by the DIAL lidar system and aircraft sampling, however, the lidar systems are subject to interferences during precipitation and flying is difficult in storms. A possible approach to this problem is to use clear air concentration profiles collected under different conditions to develop concentration profile parameterizations. It may be possible to include the measureable surface level concentration as one of the parameters. Other programs may also provide data for either concentration profiles or wet deposition rates.

3.3.5 Short-Range Experiments - Local Source Modulation

Source modulation experiments provide a direct response to questions of emissions modification effects. The large scale or deep modulation experiments contemplated in the EPA sponsored design workshop appear to be infeasible due to cost and detectability. For the combined experiment, a local source modulation is considered to study the effects of emissions changes from a small group of sources on a sensitive receptor area. This experiment does not directly contribute to the transmittance analysis but does provide a means of evaluating the source/receptor relationships developed by the transmittance approach.

In the source modulation experiment, tracer material is released continuously to establish when an air parcel that originated near the modulated source is present over the receptor region. Measurements of concentration and deposition are required over the experimental period. These measurements will be analyzed to determine the differences in concentration patterns between periods when the source is operating at different modulation levels. If the local source is a significant contributor to deposition in the region, (i.e. identifiable in the analysis), a direct source receptor relationship is established by this experiment. Munn (1984) provides appropriate techniques to identify trends in the data.

3.3.6 Meteorological Categorization of Results

Development of empirical relationships requires a measurement program which adequately samples conditions over the range of possible meteorological events. In the transmittance approach and the statistical analysis approach described in Section 3.5, the frequency of meteorological conditions play a major role in determining the source/receptor relationships and estimating confidence limits on those relationships. In the transmittance approach, meteorological frequency enters the analysis in the local deposition rates and transmittances used to calculate the pollutant mass fraction which arrives at a receptor area and is available for deposition.

3.4 Component Analysis - Modeling Approach

Current modeling approaches for evaluating source attribution have been rejected by policy planners as being insufficient due to high or unknown levels of uncertainty associated with models. Advanced regional models are currently under development to reduce this uncertainty (e.g., see Appendix A.5) but the final configuration of the models has not been determined and, more importantly, they are not scheduled to be available for planning or analysis during this program.

An alternative modeling approach is presented as a backup to determine source/receptor relationships. The approach is based on assumption that current models do provide some skill in estimating acidic deposition and that, when paired with analyses of data from an experimental program such as COMPEX, they can provide improved simulations over those models currently in use. This improvement would come as a result of model modifications in response to a better understanding of individual processes in the models, improved resolution of input data, and model validation leading to a tuned or calibrated model (Wisenfeld and Kreiss, 1982). In all three of these areas, improvements in data quality are expected to provide improvements in modeling and corresponding source/receptor relationships which are not currently possible (Ruff et al., 1984).

To date, the best regional data sets were associated with limited programs. Regional air chemistry measurements taken during the SURE program have little information on precipitation chemistry and meteorology. Later programs such as the UAPSP precipitation chemistry network (Appendix A.2) suffer from the lack of air chemistry data. Potential use of modeling as an alternative approach is described briefly in the following subsections.

3.4.1 Model Input Preparation and Use

The combined experiment will provide a data base for model evaluation and for other modeling associated with the program. Use of current models will require a data base which is a subset of the model evaluation data base.

Their data requirements are relatively simple as compared to the models under development. Potential uses of the current generation of regional models are as follows:

- Experimental Management and Control - Tracer releases and aircraft sampling will be controlled by an operations center (Section 7.0) which will also serve as a central point for data collection. The first use of the models will provide expected distributions of trajectories and concentrations for use in controlling of field operations.
- Trajectory Analysis - Trajectories will be determined by sampling of tracer concentrations released major emission source areas. Trajectory models operated using standard rawinsonde wind data and/or output wind fields from dynamical forecast models will be used: 1) as a backup for trajectories needed for transmittance, 2) to determine the probable path of tracer plumes, 3) to establish release sites for tracers, and 4) to assess the adequacy of ground level tracer concentration measurements.
- Model Evaluation and Improvement - Use of current models in developing generalized source/receptor relationships will require improvements in the models. These improvements will be provided by parameters calculated using the results of the short range experiments (e.g., deposition velocities and scavenging parameters), by comparisons and of model results with observations and modification of model parameterizations in response to differences, and by improved input data.
- Plausibility Studies in Support of Analyses - Models will be used to evaluate concepts identified in the course of determining source receptor relationships by other methods. This use of the models has been employed in some of the uncertainty studies supporting this design (Section 8.3).
- Development of Source/Receptor Relationships - Use of improved models for the experimental period will result in estimates of source attribution.

3.4.2 Model Evaluation and Improvement

Development of the source/receptor relationship from model results requires an assumption that model improvements will be sufficient to consider the models as accurate representations of the deposition processes. To make this assumption, numerous modifications should be made to state-of-the-art models. These changes will be in the form of changed parameters or model calibration and will include:

- Regionally representative deposition velocities.
- Regionally representative precipitation rates and precipitation specifications.
- Additional parameterization of wind shear.
- Modified chemical transformation parameterizations.

These modifications and others would be run in the models with time varying emissions estimates and compared to short term sequences (6 hour) of concentration and deposition measurements. Iterative model modifications and comparisons to date from the combined experiments would determine the accuracy of the model. Statistical testing would take place using parameters identified in previous model evaluation efforts (e.g. Ruff et al., 1984).

3.4.3 Use of Models in Developing Source/Receptor Relationships

The improved and/or calibrated model will be run for the experimental period using all sources and the major emissions source regions tagged by tracers in the long range tracer experiments. Results of these simulations will be analyzed to provide long term source/receptor relationships as well as arrays of short term relationships meteorological and distance classes. The second series of relationships will provide a data base for extrapolation of results of the experimental year to other years. This will be done by combining the results determined under similar meteorological conditions in a sequential input data base. The approach assumes that uncertainties in modeling can be reduced below current methods and that a one year experimental program will provide an adequate representation of conditions expected to influence deposition on a long term basis.

3.5 Statistical Approach

Statistical analysis methods can be used to estimate source contributions to observed ambient concentrations and wet deposition values from the experimental measurements. These statistical techniques do not rely upon an understanding of the various physical processes contributing to acidic deposition, but instead utilize the spatial and temporal characteristics of the observed concentration/deposition fields to identify the relative contributions of nearby versus distant source regions. The key elements of the experimentals for such a statistical approach include routine monitoring (particularly in the fine grid region), non-reactive tracer releases, and detailed emissions inventory data.

Statistical analyses offer several advantages as parallel approaches when compared to the transmittance and/or modeling approaches. For these approaches, it is important to track air parcels between the sources and receptor regions as in the long range tracer component. It is also important to characterize (through measurements) the processes which affect pollutant material balances en route. The transmittance approach may be highly sensitive to measurement uncertainties. Modeling is similarly sensitive to assumptions and the choice of parameter values for processes which are not yet adequately understood.

The advantages of the statistical approach include primary reliance on ground-level data, which can be obtained continuously and reliability, and a minimum of assumptions regarding specific process and associated parameter values. The principal limitation of a statistical approach, however, is an inability to provide an explicit source/receptor accounting of observed deposition.

3.5.1 Statistical Analyses

A number of investigators have carried out statistical analyses of regional scale air pollution, frequently oriented toward experimental design of monitoring networks. These analyses focus on the problem of estimating a pattern of concentration/deposition values, C (x, y), from a finite set of point measurements. From these concentration values, correlation statistics are computed to characterize the temporal and spatial variability. Interpolation schemes can then be utilized to generate best-fit concentration field with an appropriate covariance structure.

One simple statistical technique, Kriging, has been applied to acid precipitation data in the northeastern United States by Finkelstein (1983), using NADP data from 31 sites for 1979-80, and by Bilonick (1983) using data collected from 22 sites in New York State from 1965 to 1979. However, Kriging is only suitable for examining long-term average (e.g., annual) concentration patterns, and partial correlation is assumed to be homogeneous, (depending only on distance, not direction). Analyses of the SURE concentration data suggest this is not always the case. Kriging provides an objective method of interpolating from a set of point measurements, while explicitly accounting for measurement uncertainty.

Similar analysis techniques can be used to examine short-term concentration patterns from one or more selected episodes. Van Egmond and Onderdelinder (1981) applied three interpolation schemes to observed SO_2 concentration patterns in the Netherlands: optimum, eigenvector, and weighted interpolation. Application of such techniques to episodes of acidic deposition measurements, grouped according to meteorological and/or source transport conditions, will serve to define concentration gradients and measures of spatial varability.

Stratification by Meteorology

Grouping events according to meteorological conditions can greatly enhance effectiveness of the statistical approach and is important to all three approaches. Over widely differing meteorological conditions, spatial patterns of deposition may vary widely, but events grouped according to dispersion and chemistry should show greater similarity. Over a single year of routine monitoring, perhaps as many as 60 distinct wet deposition events will be observed within the densely gridded region. Stratification will therefore focus on a few key variables, such as temperature and synoptic meteorology, to define climatological classes. Prior studies utilizing the SURE data and historical air quality measurements have shown strong associations between elevated levels of sulfate aerosol, elevated ozone concentrations, and ambient temperature.

For an individual event, the spatial and temporal variability of precipitation may strongly affect observed results, but over a group of similar events, such random variations should average out. It is therefore, important to define groups or classes containing a minimum of 7 or 8 individual episodes, to give results which reflect spatial varability due to transformation and dispersion, rather than precipitation scavenging.

Analysis of Tracer Release Data

The inert and reactive tracer releases and concentration measurements will define the spatial concentration patterns produced by sources at distances ranging from 100 to 1000 km from the receptor region. The results from these experiments will provide the information needed to deduce source contributions from the variability of observed deposition patterns.

In a simpler fashion, statistics utilizing the inert tracer as a marker for plume transport can be used to compare observed impacts with and without contributions from a specific regions and to infer incremental contribution from the "tagged" region. Such an analysis depends strongly upon the characteristic length scale of spatial variations in emissions, and the extent to which tracer emissions simulate precursor pollutant emissions.

Draxler (1983) provided a sample analysis of the relationships of Lagrangian statistics to deposition values which would be enhanced through the use of actual trajectory data rather than calculated trajectories. Other analyses have used transport information to relate deposition values to air parcel residence times in regions with different source characteristics.

3.5.2 Direct Empirical Determination of Source/Receptor Relationships

The final product of a statistical analysis approach is a determination of a statistical model for source/receptor relationships. Direct methods determining source/receptor relationships were discussed by Liu (1984). An example of such a scheme for SO_2 is presented in this section to illustrate one possible form. Use of this approach as the primary means of analysis would require further study prior to use. Determination of the final form of these relationships, their capabilities, limitations and ultimate usefulness could be determined through studies with currently available and model synthesized data bases.

A Statistical Model For Source-Receptor Relationships

An example of a simple and commonly used statistical model of the relationship between an outcome variable, Y, and variable to be controlled, X, is the linear model. The examination of the strength of the linear association between Y and X may either show the linear model to be adequate or suggest appropriate alternative models. The following discussion is most appropriate for pollutants which are conservative or near conservative. Through appropriate stratification of data analyzed and/or error terms, very reactive pollutants could be forced into the model but the value of the model as a predictor could possibly be reduced. In either case additional studies of statistical models for this application are required.

Assume the outcome variable is the concentration of SO_2 recorded by an air monitor at a receptor location, and the variable to be controlled to be the rate at which SO_2 is emitted from a power plant in the "source region" of interest. The transport of emissions to the receptor region requires some time so that the statistical model will allow for delayed impacts or time lags at the receptor. Impacts from other sources including local background concentrations should also be considered. The simplest such model is a linear time-invariant model (also called a transfer function model) of the form:

$$Y(t) = \mu + \sum_u [a_1(u)]\ X_1\ (t - u) + \sum_u [a_2(u)]\ X_2(t - u) + e(t) \qquad (3.20)$$

where

$Y(t)$ = the concentration monitored at the receptor at time t,

μ = the average background concentration at the receptor,,

u = the lag times

$X_1(t)$ = the emission rate at time t from a source in the "source region" of interest

$X_2(t)$ = the emission rate from a source that influences Y but is outside the "source region" of interest

$[a_j(u)]$ = an error term which incorporates measurement error (at source and receptor), nonlinearities (due, for example, to chemical transformation), and fluctuations of background concentrations about their average level, μ

In the typical use of this form of model (e.g. Brillinger, 1975), the "output" variable (Y), "input" variables (X_1 and X_2), and the error term (e), are regarded as jointly stationary time series, and it is assumed that the error term is uncorrelated with the input variables. The coefficients ($a_j(u)$) represent the filtering of emissions through the atmosphere to the receptor.

It is a simple matter, mathematically, to generalize this model to include more than one receptor or more than one source of emissions per region.

This statistical model of the transfer of pollutant emissions to a remote receptor suggests the following related statistical model for the transfer of the tracer:

$$\eta(t) = \sum_u a_1 (u)\, \xi(t - u) + \varepsilon(t) \qquad (3.21)$$

Here ξ and η represent the emitted and monitored tracer, respectively, and ε is the error term. By retaining the coefficients $[a_1(u)]$ from the first model, it is assumed that the atmosphere filters the emitted tracer and the pollutant of interest in the same manner (i.e. the pollutant is near conservative). The controlled tracer emissions, ξ, can be regarded as a "signal" that is received in the form of η at the monitoring station. It is also assumed that other sources of the tracer, including background concentrations, are negligible. Slight deviations from conservation of the pollutant may be tolerable and absorbed in the error term.

The Influence of an Emission Source on the Average Concentration at a Remote Location

From Equation 3.20:

$$\mu_y = \mu + A_1\mu_1 + A_2\mu_2 \qquad (3.22)$$

That is, the long-term average SO_2 concentration, μ_y, at the receptor equals the average background concentration, μ, plus a linear combination of the average emission rates, μ_1 and μ_2, at sources 1 and 2, respectively. The coefficients of the linear combinations are

$$A_j = \sum_u a_j(u), \quad j = 1,2. \qquad (3.23)$$

The effect of reducing the rate of emission at source 1 by a factor r is to replace μ_1 by $r\mu_1$ in Equation 3.22. Thus, to estimate the reduction in the average concentration at the receptor, coefficient appearing in Equation 3.22 must be estimated.

In disucussing long-term averages, it is important to consider just how "long-term" the averages must be for reductions to become evident. That is, the underlying average concentration at the receptor may in fact be reduced but may not be apparent due to relatively large fluctuations about the reduced average. Therefore, it is important to also estimate the variance of X_1, X_2, and e in Equation 3.20.

The Uncertainty of Estimated Coefficients

The tracer experiment will entail the simultaneous monitoring of the study pollutant, tracer, and several other compounds. Focusing on the pollutant and the tracer, monitoring "on two channels," can be represented by writing Equations 3.20 and 3.21 simultaneously:

$$\begin{array}{c} Y(t) \\ \eta(t) \end{array} = \begin{array}{c} m + \sum_u a_1(u) X_1(t-u) + \sum_u a_2(u)\, X_2(t-u) + e(t) \\ \\ \sum_u a_1(u)\, \xi(t-u) + \xi(t) \end{array} \qquad (3.24)$$

If emission rates at "source 2" (i.e., at all sources potentially affecting concentrations monitored at the receptor location) are available for analysis, then the coefficients in Equation 3.22 as well as the variance of the error term, can be estimated from primary pollutant data alone using standard methods (see, for example, Brillinger, 1975). In the case of a near inert pollutant, the tracer data provide an additional means of estimating A_1 (a linear combination of the two estimates of A_1 can then be formed so that the variance of the combination is less than the variance of either estimate.)

If X_2 is not known, then both the pollutant and tracer data (both components of Equation 3.24) are required for the estimation, but the $A_1\mu_1$ term will be absorbed in the "background" coefficients, μ (and the error term in Equation 3.20 will include fluctuations of X_2 about its average value.)

One result of note from the standard method of estimation is that the variance of the estimate of A_1 from the tracer data is inversely proportional to the slow variation component (the spectrum near frequency zero) of the emissions "signal." Thus, the standard theory suggests that A_1 will be best estimated from the tracer data if the emission signal is slowly varing and is of as large an amplitude as is practical.

Another point worth noting is that the variance of the estimated long-term average concentration at the receptor is given by

$$\mathrm{Var}(\mu_y) = T^{-1}(A_1^2, s_1^2 + A_2^2 s_2^2 + s_e^2)$$

where s_1^2, s_2^2, and s_e^2 refer to the "slow component" of the variance (the spectrum at frequency zero) of x_1, x_2, and e, respectively. Reducing X_1 by a factor r results in s_1^2 being replaced by $r^2 s_1^2$. Therefore, the standard deviation of the estimated mean concentration resulting from emissions reductions at source 3.20 will be reduced, but not by as large a factor as the mean being estimated. The period required to verify the reduced concentration level may therefore be somewhat longer than the period required to accurately establish the level prior to the emission reductions.

SECTION 4

LONG RANGE TRACER EXPERIMENTS

The long range tracer experiments are major elements in the comprehensive design and provide:

- Information on pollutant transport and dispersion of emissions over distances of at least 1000 km.
- An estimate of the potential contributions from major emissions source regions to concentrations at a sensitive receptor and locations on a sampling grid.
- A definitive answer on sources which do not contribute to deposition at receptors on an episodic basis.
- Mass flux estimates for tracer and pollutant concentrations relative to a limited receptor area.
- Estimates of total sulfur loss over a limited area.

When the long range tracer information is combined with routine monitoring data, the result will add information on the temporal and spatial patterns of tracer concentrations relative to measured sulfur oxides. These data will be analyzed to infer source contributions, to determine the area of influence from each emissions area and to evaluate components of regional models.

The following sections describe the tracer releases and sampling under this component of the study. Figure 4-1 shows that approximate area of study.

4.1 Tracer Releases

The proposed design uses inert long range tracers to estimate the transport and dispersion of pollutants. Constraints of available tracers, the length of experimental period, and meteorology are considered in specifying release sites, frequencies, configurations, and amounts. A critical question is whether a sufficient number of samples can be collected during a one-year experimental period to provide a robust data base for the developing empirical

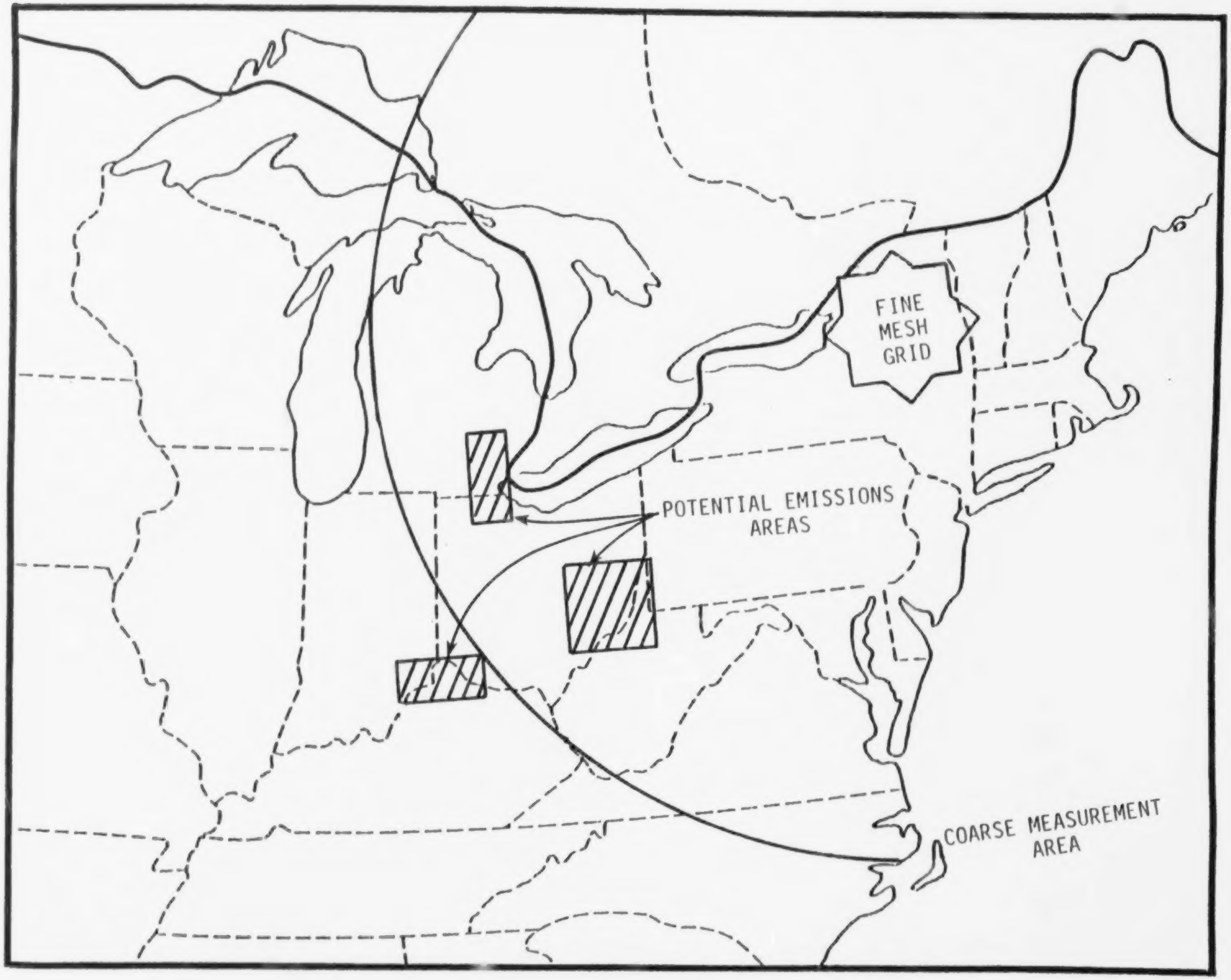
FINE
MESH
GRID
POTENTIAL EMISSIONS
AREAS
COARSE MEASUREMENT
AREA

Figure 4-1. Emissions and sampling areas for the combined experiment.

source/receptor relationships. The adequacy of the data base will be determined primarily by meteorological conditions occurring during the year. Operational considerations on tracer releases also play a role in determining if data will be collected under all important periods during the experiments. The objective of this section is to describe a flexible plan for tracer releases which will provide the highest number of sample episodes.

4.1.1 Tracer Release Areas

The proposed study will use data collected on a sampling grid centered in the Adirondacks and extending approximately 1000 km. The prevalence of westerly and south-westerly winds in the area and the preponderance of large emission source areas suggests that the release points for a tracer study should be to the west and southwest. Constraints, such as the costs of tracers and the risk of losing the identity of individual tracer releases, when combined with the actual frequency of winds in a given direction, suggest that such a plan would not provide a sufficient number of sample episodes to develop an adequate empirical source/receptor relationship. Preliminary model simulation results (Section 8.3) and results of the ACURATE* experiments (Hefter et al., 1984) confirm this difficulty. Analyses were performed using a regional transport model simulating the detectability of inert tracers emitted in the Ohio River Valley at receptors in the Adirondacks for a one month period. Results indicated that detectable concentrations would be observed at most approximately 40 percent of the time. ACURATE results (Section 8.3) indicated that the probability of a single source influencing a single receptor is an inverse function of distance. Frequencies in the experiment were in the range of approximately 10-30 percent. To increase the frequency of tracer impacts, it is proposed that tracer release points circle the receptor area in directions of significant emissions.

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*Atlantic Coast Unique Regional Atmospheric Tracer Experiment

The availability and costs of long range tracers limit the number of emission source areas which can be uniquely identified with an inert tracer. Three tracers with long range capabilities expected to be available for this study, although up to eight have been suggested. Of the three most readily available, one is proven, one has not been tested in similar applications and the other is less desirable due to marginally higher costs and significantly higher release rates required due to a higher natural abundance (Dietz and Senum, 1984). For cost efficiently, two tracers are recommended and any additional tracers are considered optional. Use of additional tracers would minimize the risk of a tracer not influencing the primary receptor area as a result of meteorological variability. The effects of meteorological variability are lessened in the design by using of forecast controlled tracer releases from source areas surrounding the primary receptor area.

Sites identified as potential release areas will be selected from major emissions areas as determined with an SO_2 emissions inventory, (Figure 4-2).

4.1.2 Distributed Source Releases

The desired source/receptor relationships will represent the contributions of major source regions rather than individual point sources. This requires that tracer releases be distributed over areas rather than being made from a single point. The workshop participants identified the scale of major emissions source regions to be on the order of 100-200 km. This determines the area over which the tracer releases should be distributed. The size of these areas and the need for continuous releases over long periods preclude the use of techniques such as aircraft releases.

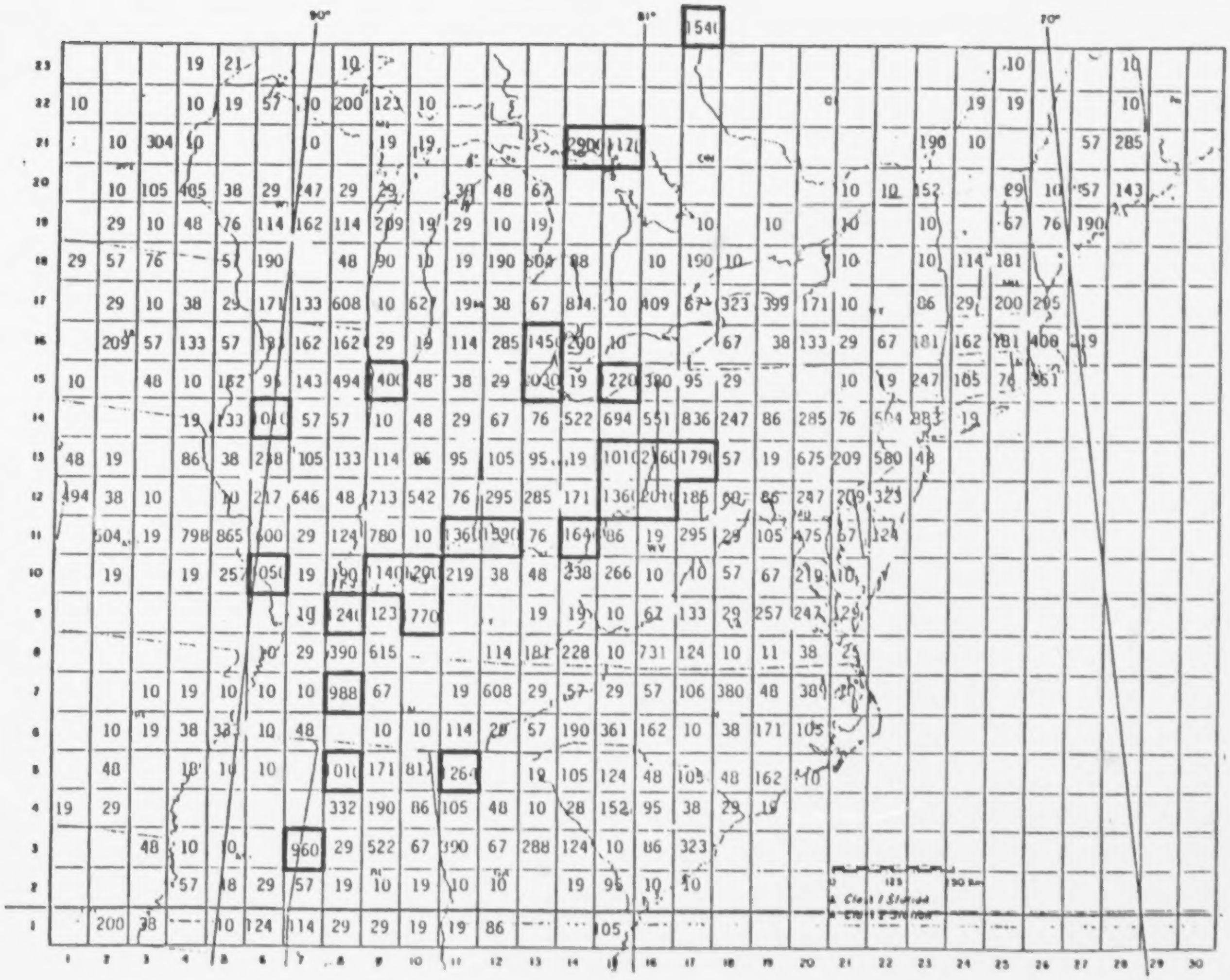

90°
81°
70°
1540
2900
1120
WV
Class I Station
Class II Station

Figure 4-2. Sulfur dioxide emissions for summer 1977 in Mt/day for each 80 x 80 km grid, from SURE Program, Perhac et al (1981).

Emission areas will be simulated by a collection of point sources. This type of release plan has the advantage of providing a stationary grid of release sites from which emissions can be better regulated. The major difficulty with this technique is that numerous release points are required to represent the actual emissions distribution unless horizontal dispersion is large. Logistically, this represents an accuracy tradeoff in source term definition versus the cost of individual tracer release sites. The proposed design uses five release points to represent each emissions area. Releases will be made from large emission source stacks to inject the tracer material at heights representative of the emissions source distribution. Stack injection should be monitored to avoid biases associated with deterioration of the tracer temperatures above 200°C. The release points will necessarily follow the non-uniform distribution of sources, but an attempt should be made to select sources on the area boundaries and at the centroid. The number of points could be reduced if the emissions area of interest is dominated by a single source such as the Sudbury smelter complex. Five sites per source area were selected as a compromise of number versus emissions source uniformity. With a 100 to 200 km emissions area, it is expected that individual tracer plumes would typically merge in a uniform wind field at a distance of approximately 200 km from the release points. This is consistent with the sampling grid resolution.

The question of point or distributed releases was studied using a regional model (Section 8.3). Model simulations indicated that distributed releases provide significantly different concentration patterns than those obtained from point sources. Use of distributed releases increases the potential for sources to influence the receptor area and therefore the frequency for which data can be collected in one year experimental program.

Distribution of emissions by height and location within a major source area will be determined by the emissions of sulfur oxides relative to the area totals. Records will be maintained of emissions at the sources used for tracer injections and at other major sources in the emissions areas.

4.1.3 Tracer Release Mechanisms

The inert perfluorocarbon tracers identified for possible use in the experiments are:

- Perflourodimethylcyclohexane (PDCH)
- Perfluoromethylcyclohexane (PMCH)
- Perfluoromethylcyclopentane (PMCP)

PMCH and PMCP are suggested for use. Characteristics of these and other potential tracers have been described in a paper by Dietz and Senum (1984). PMCH and PDCH have been used previously as tracers in long range pollutant transport experiments. PMCP has characteristics which will allow its use in this study, but it will require testing prior to use. The release mechanisms for all three tracers are the same and are similar to those used in the CAPTEX study (Ferber and Heffter, 1983). Modifications to the mechanisms may be required to assure successful operation over a long time period. The release mechanisms function by vaporizing liquid tracer carried in a N_2 gas stream and metering the resulting gas stream prior to release. A secondary check on the tracer release is provided by weighing the tracer cylinder before and after release. For the distributed releases, the tracer and carrier stream will be released in a stack test port.

4.1.4 Schedule of Tracer Releases

Releases of the non-reactive tracer will be made continuously for 24-hour periods every three days for a year. The 24-hour release time is designed to provide long releases for ease of detection without introducing a bias related to the diurnal meteorological cycle.

The three-day release cycle has multiple purposes. The first is to provide a large number of samples from a broad range of meteorological conditions while conserving tracer material for cost reduction. It will also create a modulation of the tracer sources to produce breaks in the tracer clouds which will be used with wind data in analyzing transport from tracer time histories. Without such a distinguishable breaks in the tracer concentrations or continuous aircraft monitoring, it would be difficult to observe the timing of tracer transport in the proposed program.

CAPTEX experience indicated that with relatively short tracer releases (three hours), the potential exists for fragmenting the tracer plumes. In six of the major CAPTEX releases a distinguishable and traceable tracer pattern could be detected and a combination of sequential patterns allowed a definition of the tracer transport path. In one case, there is evidence of transport split between two paths. This indicates that the tracer cloud resulting from a release of 24 hours or longer will, in almost all cases, result in multiple tracer plume segments. Tracing the discontinuities represented by these segments provides a higher number of trajectories for each release which have the potential of being transported to the target receptor area. Tracer releases in excess of 24 hours would also provide multiple plume elements, but would not provide additional information on the effects of the diurnal cycle. A two-day gap between tracer releases is provided to allow residual tracer material to clear from the study area and to conserve tracer resources.

4.1.5 Tracer Release Rates

Release rates for the perfluorocarbon tracers are determined on the basis of expected tracer dispersion. Sampling resolution and release rate are very closely tied such that decreases in release rates require an increase in the number of samplers to adequately detect the plumes. In the CAPTEX study, tracer plumes were detected which were as narrow as 30 km in width, 1000 km downwind. Preliminary model results indicate that use of distributed releases over emissions areas of 100 to 200 km in scale should reduce the risk of not observing tracer plumes. Plume detectability is also a function of the plume concentration versus the natural background concentrations of the tracers in question. The target ratio of plume center line concentration to background concentration for this study was initially set at 100 to assure a detectable plume at downwind sampling sites. Model simulations indicate that a factor of ten will be acceptable.

The background concentrations of PMCH and PMCP are approximately 3 fl/l and for PDCH, the third tracer considered, the background is approximately 26 fl/l (Dietz and Senum, 1984). Tracer release rates can be determined by conversion of the concentrations into mass units and dividing the expected relative dispersion X/Q into the background value (Michael, 1984). The final release rate is then determined by multiplying this ratio by the target ratio of plume to background concentrations which for this study has a value of 10. In its simplist form, the relative plume dispersion can be given by:

$$X/Q = \frac{1}{u\ H\ x\ \tan A} \qquad (4.1)$$

where:
u = mean transport wind speed (m/s)
H = mean mixing height along the transport route (m)
x = downwind distance (m)
A = angle of plume dispersion

The values assumed for these calculations are a wind speed of 10 m/s, a mixing height of 1000 m, a plume spread angle of 10°, and downwind distances of 500 to 1000 km depending on source/receptor separation distances. For various separation distances, the required PMCH and PMCP releases rates for ratios of 10 times the background concentration are:

	Release Rate (kg/h)
Separation distance	10 x background
1000 km	3.4
700 km	2.4
500 km	1.7

Results of the CAPTEX study indicated that emissions of 50 kg/hr of PMCH (Dietz, 1984) would result in tracer concentrations 100 times background at 1000 km. This rate is in essential agreement with those above for similar constraints and will be used as the reference for PMCH and PMCP estimates in this design document.

Release rates were studied further with a regional dispersion and transport model to assess tracer detecability. The model results compared the frequency of time tracers were detectable and tracer emissions rates as multiples of background concentrations. The results (Section 8-3) indicated that detectability at any emission rate was limited by transport winds at a frequency of approximately 40 percent. In addition, the results indicated that distributed emissions had, in general, a higher frequency of detection and the frequency was most sensitive to the concentration multiplier over background concentration at emissions of below 10 kg/h. This last result in conjunction with the CAPTEX results indicated that a tracer release rate of 10 kg/h is a reasonable estimate for tracer detectability.

The higher background concentrations of PDCH would require a release rate almost an order of magnitude larger to assure dectability, and therefore, it is not proposed as a primary tracer.

For estimates of the total release amounts, it is assumed that source/receptor separation distances would be approximately 1000 km. Tracer requirements for each tracer are:

10 kg/hr (at 1000 km) x 24 hr/release x 121 releases per year = 29 tonnes

4.2 Sampling

The following subsections describe sampling grids and techniques for use in the long range experiments. Measurements under this component include tracer sampling on a nested grid system as well as aircraft measurements of tracers and pollutants to support transmittance or mass balance estimates in the vicinity of a sensitive receptor.

4.2.1 Grid Location and Resolution

The proposed location for a nested tracer sampling grid for use in long range tracer experiments is given in Figure 4-1. The grid consists of a coarse resolution sampling grid designed primarily for collecting data on transport and dispersion and a fine resolution subgrid over which detailed information on near receptor effects and mass distributions can be studied. Tracer sampling and routine monitoring of air and precipitation will take place on the same sampling grids and the following discussion is also applicable to siting the routine monitoring network (Section 6.1). The location and extent of the sampling grids was determined by considering the Adirondacks as the primary sensitive receptor area and the need to study the effects of emission sources at distances of a scale up to 1000 km. Other areas could be used for the study by changing the locations of the grids. The assumption of a 1000 km transport distance was made under the following considerations:

- The source/receptor relationships developed under the design are intended to represent conditions in the Eastern U.S. and Canada rather than exclusively the path between major sources and the Adirondacks region.
- A 1000 km scale is representative of synoptic scales of meteorology.
- Transport times for tracers released on a 1000 km grid are sufficient to demonstrate the effects of diurnal cycles.

The sampling area for the coarse grid is that portion of a circle surrounding the receptor area in directions defined by the location of major emissions areas expected transport paths.

The resolution of the coarse tracer sampling grid will be non-uniform but will average 100 to 130 km. Grid resolution estimates in following discussions do not consider sites over water or in inaccessible areas. As is the case in most field sampling projects, this resolution is a compromise between desired resolution and a reasonable number of stations. The sample spacing is consistent with the scale of major emissions areas, meteorological variations on the mesoscale and the transport times expected to correspond with a six hour sampling interval. The sampling network is not sufficient to detect variability in primary pollutants near the emissions sources.

A review of the ground level sampling data from the CAPTEX program suggests that sampling of tracers with a 100 km grid spacing is marginal. CAPTEX sampling was conducted on arcs approximately 100 km apart with sampler separation on the arcs related to predicted tracer plume widths. Tracer releases were made from single point sources Preliminary results reviewed in developing this plan suffered from missing data but, in general, showed the location and concentrations of tracer plumes. Distributed tracer releases in this design are expected to increase the detectability of tracer plumes (Section 4.1.2) and the acceptability of the suggested sampling resolution.

In place of a uniform coarse sampling grid, it is proposed that sites selected for tracer and routine monitoring be a collection consisting of some former SURE sites, current precipitation chemistry network sites, and additional sites to fill gaps as required (Figure 4-3). This monitoring plan will help in extending the results of the program by allowing data analyses in the context of previous and ongoing programs. The COMPEX program is of limited duration and this plan will compensate for a short sampling period by analyzing the results in terms of previous long term measurements. Part of operational planning will include final site selection. This will involve an evaluation of which former or existing sites would be used without overlapping measurements. After available sites are reviewed, additional sites will be added to provide adequate network coverage. It is expected that roughly 100 sites will be required to provide the desired sampling resolution. This estimate does not include sampling in areas where siting would be excessively difficult.

The fine resolution subgrid will cover an area including a critical receptor region in the Adirondacks (Figure 4-4). The primary function of sampling on the grid is to provide data for describing tracer mass distributions and for calculation of mass balances in a limited area. Measurements include ground level tracer sampling and routine air and precipitation chemistry monitoring, remote sensing of wind and concentration profiles, rawinsonde measurements of temperature humidity and wind profiles, and aircraft sampling of tracers and air chemistry.

The proposed area for fine grid sampling is centered in the Adirondacks and encompasses a zone roughly 240 km in radius. Measurements and calculations will be made in an approximately square area of 200 km on a side within the circle. Ideally, the square would be oriented with the transport

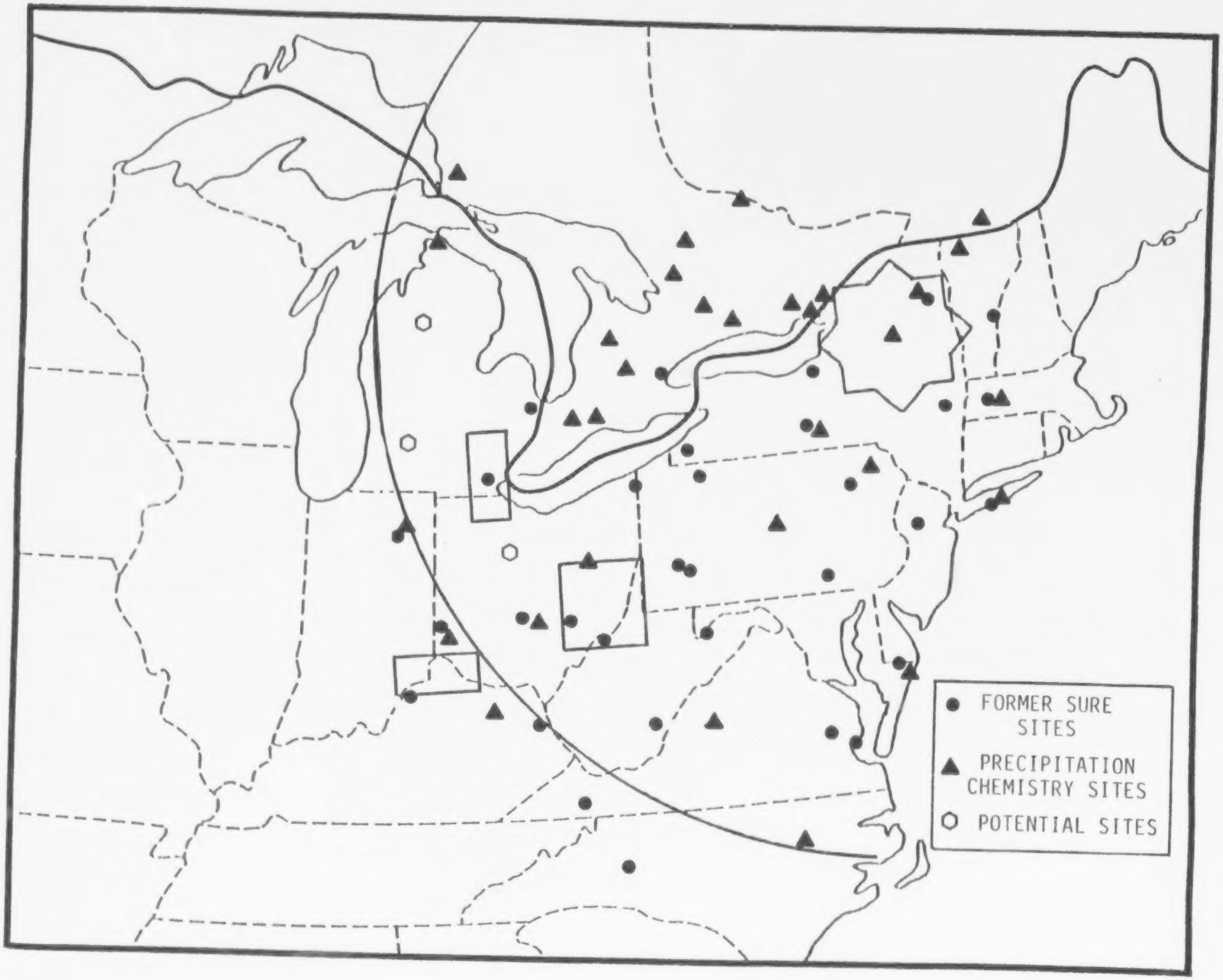
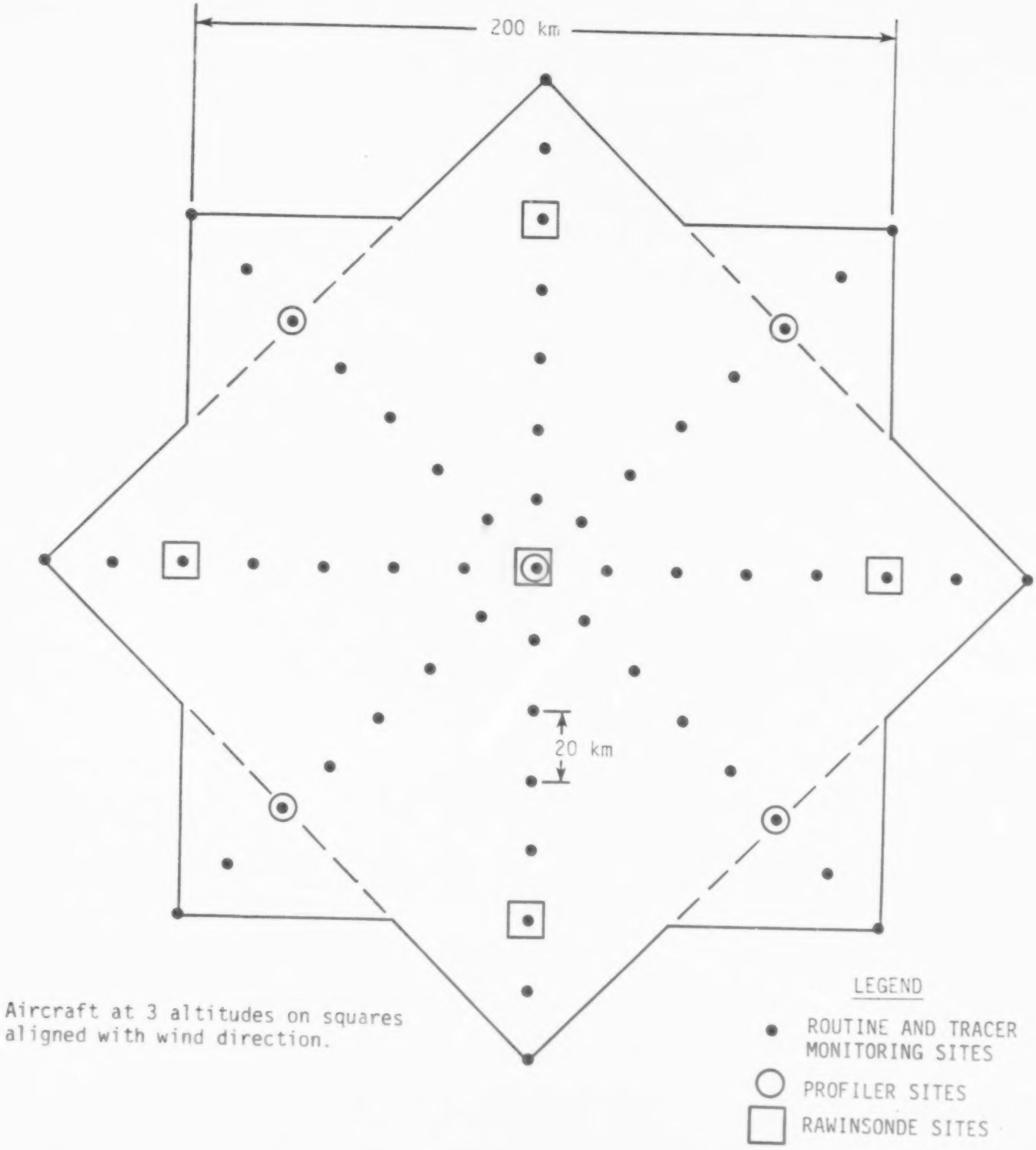

● FORMER SURE SITES
▲ PRECIPITATION CHEMISTRY SITES
○ POTENTIAL SITES

Figure 4-3. Potential sites for tracer and chemical measurements for the combined experiment.


200 km
20 km
LEGEND
● ROUTINE AND TRACER MONITORING SITES
○ PROFILER SITES
□ RAWINSONDE SITES

Aircraft at 3 altitudes on squares aligned with wind direction.

Figure 4-4. Fine mesh sampling grid.

wind direction for mass balance calculations but this is impractical for a fixed ground level monitoring network. The network shown in Figure 4-4 considers wind orientation by including sites within squares oriented parallel to meridians and at a 45° angle. This creates a fixed grid in a radial configuration with sensors on eight radial wind direction sectors from the center of the receptor area. The area of the fixed grid and its location were selected for the following reasons:

- The grid area is of the scale of the major emission sources of interest.
- The grid dimension is of a size over which measurements for mass balance calculations are feasible.
- The area covered includes the Adirondacks receptor area identified as the most sensitive to acidic deposition.
- The size of the grid is of the scale of major mesometeorological systems which would influence wet deposition.
- The area dimensions are sufficiently small to allow the practical use of aircraft for sampling.
- The dimension of the grid is of the same order as transport distances expected for pollutants measured with a six hour sampling period.

The sample spacing for sites on the eight radials is 20 km which results in a range of intersite separations from approximately 20-100 km. These spacings are consistent with recommendations of the EPA sponsored design workshop which recommended that the maximum separation for precipitation sampling sites be 80 km. In addition, results of the SURE program led to recommendations that grid spacings of less than 50 km would be required to adequately detect variations of primary pollutants on a regional scale (Perha et al., 1981). This spacing requires 57 sites to be monitored Some modification of the grid configuration is possible to provide more even resolution between the inner and outer sectors.

4.2.2 Ground Level Sampling Techniques

Ground level tracer sampling will use a sampler such as the Brookhaven Atmospheric Tracer Sampler (BATS). The automatic sequential sampler (BATS) for perfluorocarbons consist of an Air Flow Module (lid) and a Power Control Module (base). The sampler contains 23 sampling tubes filled with Ambersorb which traps all the perfluorocarbons (absorption) in the air flowing through the tube. The tubes are operated in a sequence controlled by a internal digital clock. The limit of detection for the sampling is 3 ppt. After 23 samples have been collected, the lids are removed for laboratory analysis while a fresh lid is attached in its place to continue the sampling program (Ferber and Heffter, 1983).

The procedure for sample lid collection will be determined after the final network configuration has been established. The objective of the protocol is to assure controlled collection of the sample lids with sufficient numbers of lids available for each site to maintain a continuous sampling program.

The laboratory analysis of samples is a proven technology used in the CAPTEX and other studies using PDCH and PMCH. The laboratory analysis of the third tracer, PMCP, will require demonstration before use. Samples collected will be analyzed using an automated gas chromatograph. Automated systems will soon be available with microprocessor control and data handling and up to four gas chromatographs to allow processing of 5 to 20 lids per day or up to 460 samples per day.

The design requires the use of 157 samplers which will be programmed to sample tracers every six hours. The required laboratory capacity for sample processing is 628 samples per day without consideration of aircraft sampling requirements.

4.2.3 Sampling in the Receptor Area

In addition to ground level sampling of tracers on the coarse grid, the long range transport experiment design includes fine resolution measurements of pollutants, tracers, and wind profiles. These measurements will characterize the near receptor environment and examine the depletion of mass in an area as described in the analysis for the transmittance (Section 3.3). The experiments will include the use of rawinsondes and remotely sensed wind and pollutant concentration profiles as well as aircraft data to support transmittance estimates.

Rawinsondes will be used to provide wind, temperature, and humidity profiles from five sites within the fine resolution grid. These will provide information on wind components, mixing and cloud base levels and stability. During periods when mass balance experiments are conducted, rawinsonde releases will be made every three hours.

Profile information on winds and pollutant concentrations will also be available as a result of continuous remote measurements on the fine resolution grid. Remote sensing sites will be located (Figure 4-4) at the fine mesh grid center and at the corners 100 km from the grid center. Rawinsonde, tracer, air, and precipitation chemistry measurements will also be available at the sites. Wind component measurements will be made using a lidar system patterned after that of the NOAA Wave Propagation Laboratory (Hall et al., 1984). These systems are capable of measuring winds continuously in layers except during periods of precipitation interference. When combined with corresponding concentration profiles, local estimates of pollutant flux can be calculated. In addition, data analysis by pairs and triplets will provide enhanced accuracy and extensive lateral and vertical coverage.

Concentration profile measurements for O_3, SO_2, and aerosols (relative concentrations) are possible using the DIAL dual laser system. DIALs scans can provide concentration profiles with 45 m range cells with a limit of detectability for SO_2 of 5 ppb in 200 m. Since it will be difficult to determine concentrations and deposition rates for sulfur species without a reliable estimates of chemical conversion rates, some estimate of sulfate concentrations will be required to estimate total sulfur losses. One possible method will be to assume that sulfate concentrations can be determined primarily using aircraft data. Review of the aircraft profile data with the DIAL pollutant profiles will identify problem areas caused by atmospheric layering.

Aircraft sampling will include measurements of aerosol sulfates and nitrates, SO_2, nitric acid, NO_x, ozone and the two perfluorocarbon tracers. The measurement flights will be directed by the project control center during favorable conditions for mass balance estimates. The flight paths used in the studies will be perimeters of the fine mesh grids and interior paths flown by multiple aircraft at three levels in the vertical. The determination of the flight path heights will be made on the basis of the vertical atmospheric structure measured in real time by the DIAL systems. Coordination of flights will be provided so that each measurement episode will be represented by a flight at the beginning and end of the experimental period.

Measurements provided for transmittance or mass balance calculations should ideally be for steady state conditions although this condition is difficult to obtain in the atmosphere. The program as designed will make vertical measurements over a 200 km square area in the atmosphere. The scale of measurements was suggested to be large enough to show depositional losses in excess of measurement uncertainty but small enough to represent a relatively steady portion of a tracer plume from distant sources. To further control the experiments, additional tracers in the form of constant density balloons or tetroons will be used to mark the approximate positions of the air masses being sampled. The marking will be performed by releasing multiple tetroons with transponders along the windward face of the fine grid during the first aircraft measurements. These balloons will be tracked and an attempt will be made to conduct the second series of flux measurements at the time the tracer balloons arrive at the lee side of the sampling grid. Tetroons themselves have performance limitations such as groundings caused by moisture, gas losses, and other effects. This use of the balloons will correspond to the operating limitations of lidar and aircraft systems and will be used over a relatively short distance. With these limitations it is expected that the actual tetroon use will be under conditions which are optimum.

Sampling resolution with the aircraft will be limited by sample times for the tracer and filter measurements along with the speed of the airplanes. Perfluorocarbon tracers will require sampling times on the order of 5-6 min which correspond to sampling resolutions of 20-30 km. Filter measurements for air samples in the Adirondacks region will require sampling times on the order of 30 minutes which will result in integrated samples on the order of a hundred or more kilometers.

The last element of the mass balance estimates is a determination of pollutant losses by wet deposition. The primary measurements for estimating wet deposition will be the fine mesh network of precipitation chemistry samplers. Sampling resolution for the fine mesh grid was selected in part to provide an adequate description of precipitation events. Even with these condiderations, the high spatial and temporal variability of precipitation requires supplementary measurements. The method selected for the COMPEX design is to supplement precipitation and precipitation chemistry measurements with obsevations using weather radar. The radar data provide additional information on the spatial coverage of precipitation. Use of this data along with amount and concentration information from the precipitation chemistry measurements will allow an estimate of total pollutant flux out of the area by precipitation scavenging.

4.2.4 Support Data Collection

Meteorological data collected for the long range tracer component will serve primarily to identify the initial transport characteristics of the tracer plumes. They will also describe transport paths and enroute characteristics through an analysis of wind profile data and the time histories of tracer concentration patterns. Measurements for the initial transport description will be taken using a continuous wind system such as a Doppler acoustic wind system located in each emissions area. They will provide data on winds at tracer release heights to establish initial trajectory segments. Data for description of the regional wind fields from wind profiles are to be taken by a rawinsonde network described in Section 6. A potential analysis alternative for definition of regional wind fields is use of dynamical model output such as from the NWS limited area fine mesh (LFM) model.

SECTION 5

SHORT RANGE EXPERIMENTS

The short range experiments are designed to measure deposition in the range from 10 to 100 or 200 kilometers from the source. The uncertainty of the measurements and questions of areal representativeness require parallel and redundant measurements. An additional experiment is proposed to demonstrate the effects of emissions reductions on deposition.

The short range experiments described below include:

- reactive tracer experiments
- deposition inference experiments
- deposition estimated from flux differences
- local source modulation experiments

Deposition is a function of pollutant, surface type, and the meteorological rate of material delivery to the surface. Measurements will be made in a variety of terrain and vegetation settings. The first location is specified to be part of the mesoscale study region in the Adirondack Region.

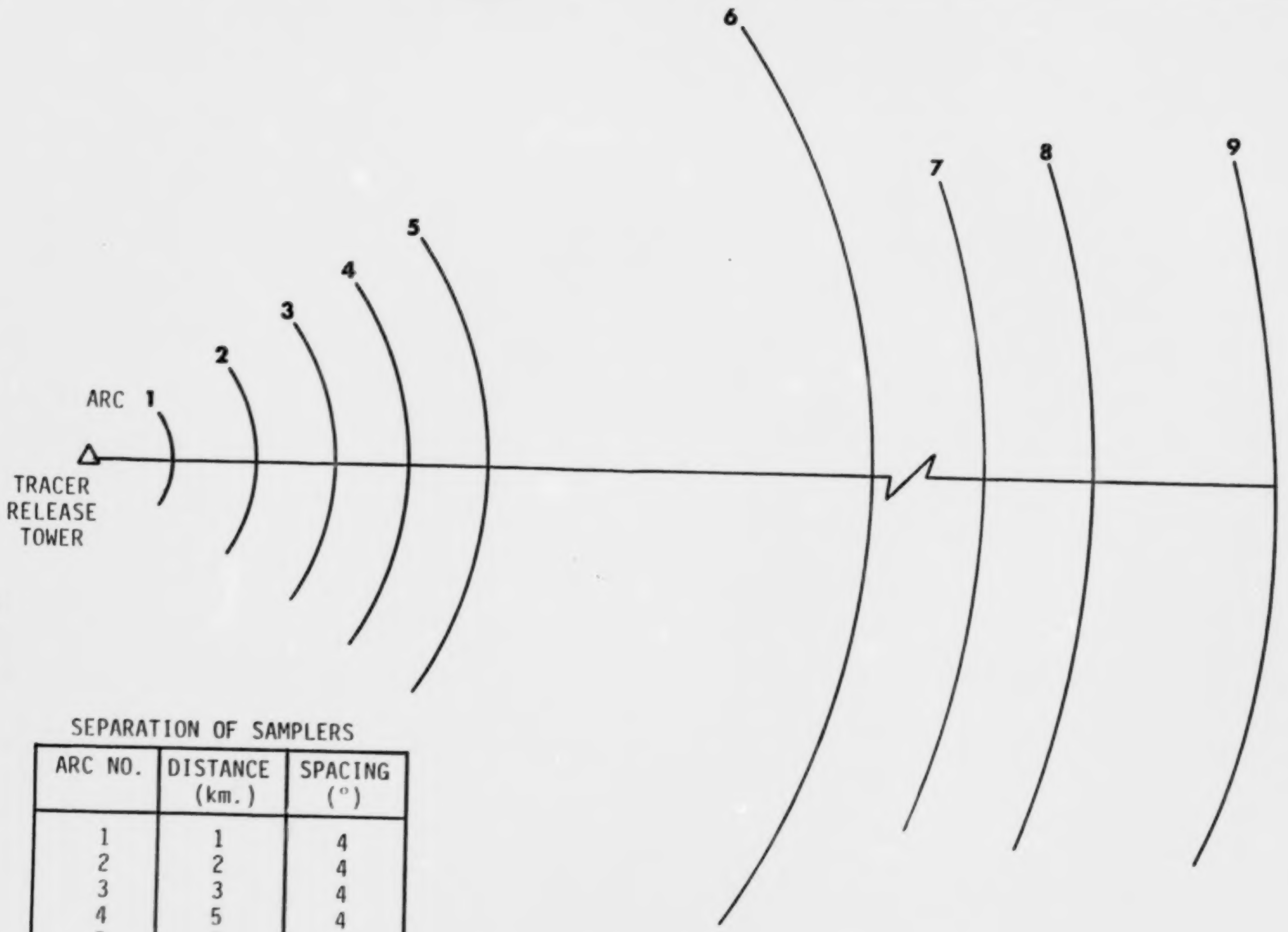
5.1 Reactive Tracer Experiments

Non-radioactive isotopes of sulfur and nitrogen occur naturally and through artificial enrichment they may be used to provide a direct measure of loss and conversion of material released from a source. Sulfur-34 (^{34}S) occurs as 4.3 percent of total natural sulfur and has very small variance around its mean values. Release of sulfur dioxide with ^{34}S enriched to 10 percent provides a tracer that can identify air parcels passing through dispersion, transformation, and deposition processes. Nitrogen-15 (^{15}N) is a similar isotope that might be used to follow conversion and deposition of nitrogen compounds. The experimental design is aimed at sulfur compounds.

A basic component in the experimental program is the use of conservative and reactive tracers to estimate dry deposition losses for a variety of surface, land use, and meteorological conditions. The experiments will be intensive studies taking place during the experimental period, but operationally independent of the long range tracer and routine monitoring components. The experimental measurements will be made on a fixed sampling grid with fine resolution within approximately 10 km of the release point and more coarse resolution for distances up to 50 km (Figure 5-1). Resolution will be determined as a function of surface type with guidance from pilot studies.

Experiments will utilize a surface depletion technique or model. For example, surface depletion techniques described by Horst et al. (1983) utilize elevated reactive and non-reactive tracer release to estimate deposition losses from elevated pollutant plumes. The advantage of these techniques is the ability to measure plume depletion with surface sampling. The techniques require theoretical assumptions of stationarity and homogeneity of turbulence which limit their applicability to distances generally less than 10 km under ideal experimental conditions. This type of analysis can be combined with an analysis of reactive versus conservative tracer ratios at distances beyond ten kilometers to extend the usefulness of the tracer releases for deposition studies.

The tracers released from an elevated source will be sulfur-34 in sulfur dioxide and sulfur hexafluoride (SF_6) with a concurrent release of a fluorocarbon (e.g., Freon) at the surface. The tracer release procedure will allow the collection of data for surface depletion and depletion budgets (e.g. Horst et al. (1983)) for distances within about 10 km. The technique provides a deposition estimate by considering plume depletion represented by the ratio of reactive and inert tracers. The diffusion of clean air into the depositing plume is represented by the surface release of a second inert tracer.


ARC
1
2
3
4
5
6
7
8
9
TRACER
RELEASE
TOWER

SEPARATION OF SAMPLERS

ARC NO.	DISTANCE (km.)	SPACING (°)
1	1	4
2	2	4
3	3	4
4	5	4
5	7	4
6	10	4
7	20	6
8	30	6
9	50	6

Figure 5-1. Sample fine resolution fixed grid for deposition measurements.

The mixed resolution grid is selected to provide high resolution data for estimates by the surface depletion technique. Ratios of inert to reactive tracers will be used in deposition estimates beyond distances of 10 km. Chemical transformation of SO_2 to sulfate may be seen in data particularly at distances well beyond 10 km. The magnitude of the conversion of the isotopic SO_2 is not expected to be large over the range of the experiment, but it will be investigated.

The intent of the deposition measurements is to provide an estimate of plume deposition losses which can be used with confidence to determine source/receptor relationships in the transmittance approach. As such, it is important that these experiments along with those in the following two sections provide deposition estimates over the broad range of surface, meteorological and chemical conditions experienced by pollutant emissions en route to sensitive receptor areas. For the long averaging times and the spatial scales of the desired source/receptor relationships, the experiments need to consider both the deposition velocities of pollutants over particular surface types and the average deposition expected for composites such as forested flatlands, rolling hills in crops, or wooded hills and mountains. The deposition experiments must also represent diurnal and seasonal effects, in particular the effects of snow cover.

5.1.1 Tracer Releases

The three experimental tracers will be released as gases with sulfur-34 released as isotopic $^{34}SO_2$ in a volume of total SO_2 at a 10% enrichment rather than at the background of 4%. Sulfur-34 releases represent a new technology which requires testing prior to widespread use in a large experimental program. The two conservative tracers are widely used in atmospheric tracer studies and represent existing capabilities.

Sulfur-34 is a very stable isotope in the atmosphere with a natural abundance represented by a $^{34}S/^{32}S$ ratio of approximately 4%. Newman et al. (1975a, b) presented data with a ratio of 4.319% ± 0.0091%. Since the variability is very small, it is possible to design a tracer experiment where the target concentrations for calculating the tracer release rates need only to exceed the variability by some factor rather than exceeding the total background in areas of low background concentrations. For this study a factor of 10 times the background concentration has been selected as the target concentration for detectability of the tracer plume. This assumption was made in part because of a limit to the sulfur-34 potentially available for the study. Production limits without major investment in new or modified facilities appear to be approximately 300 kg of sulfur-34 per year (Binkowski, 1984). Since the experiments are for limited spatial scales, required release rates were calculated for plume travel distances of 20 to 50 km. To determine the tracer release rate, the background concentration was divided by the relative dispersion adjusted by dry deposition losses over fixed transport distances. Sulfur losses were estimated to be at a rate determined by a dry deposition velocity of 1 cm/s.

Final calculations of release rate follow Hicks (1984). Assuming a background sulfur concentration of approximately 13 ug/m^3 and a variability of 0.0091%, the sulfur-34 background variability is 1.18 ng/m^3. Considering the relative deposition and depletion calculated in Section 4.1.5 and adjusted to represent 20 to 50 km, the required release rate is approximately 1.6 to 4 kg/hr. This rate must be available from the enriched portion of the sulfur, i.e., the difference between the natural levels (4%) and the enriched level

(10%). This requirement results in a release rate of sulfur enriched to 10% sulfur-34 of 2.7 to 6.6 kg/hr. This corresponds to enriched SO_2 release rates of 54 to 132 kg/hr.

The required release rates in combination with the availability of tracer limit the distance over which the experimental releases can be made. For the near source experiments it is unlikely that plume sampling will take place at distances in excess of 20 to 50 km. At these distances it will be possible to conduct approximately 110-20 km or 45-50 km, experiments within the current annual production amount.

SF_6 was selected as the corresponding conservative tracer for elevated releases. Although it is commonly considered for more local studies, the scale of the sulfur-34 experiments makes SF_6 an adequate choice if the experiments, are carried out in a rural setting. SF_6 background in rural areas is approximately 2 ppt. Background in urban areas and near SF_6 storage and production areas can be 5-10 ppt or higher. The required release rate for SF_6 is calculated as in the previous sections based on relative dispersion for a tracer plume without deposition and a concentration of 100 times the rural background. At distances, of 20 to 50 km, the resultant release rates are approximately 165 to 400 kg/hr. The third tracer will be released at the surface for the experiments which will require detectability at 10 km.

Releases of all three tracers will be made from the same location with SF_6 and sulfur-34 released from a tower up to 100 m high and the third tracer released at the surface.

5.1.2 Tracer Sampling

Sampling for the conservative tracers can be accomplished using syringe samplers, bag samplers, and/or evacuated bottles filled by flow through a critical orifice. Sulfur dioxide and sulfate measurements, from which isotopic sulfur mass ratios will be determined, are collected using high volume sampling through filter packs (Newman et al., 1975a,b). The filter packs consist of acid washed quartz filters for aerosol capture backed up by carbonate impregnated cellulose filters for collection of sulfur dioxide. The rate of sample collection and the duration of sampling needs to be evaluated on the basis of expected sulfur oxide concentrations to assure sufficient sample size for analysis. It is desirable to perform all sampling using an automated sequential samplers. Development of such techniques will be required.

Sampling during intensive periods will study deposition effects for a variety of surfaces during different seasons and times in the diurnal cycle. Surface depletion techniques will provide sampling results representative of deposition velocities and depletion over small uniform areas. Sampling for the reactive/conservative tracer ratio up to and beyond approximately 10 km will provide data representative of losses and surface variability over larger scales. The maximum distance for sampling from the tracer point release is 50 km. This distance was selected to assure a sufficient number of samples to provide an adequate data base for analysis. In addition, it provides a better scale for control of the deposition experiment in terms of surface uniformity and transport relative to a fixed monitoring grid. Sites selected will be in areas of low background sulfur oxide concentrations to avoid difficulties in detecting the sulfur-34 tracer concentrations.

5.1.3 Laboratory Analysis of Samples

Experiments in this component will provide samples of fluorocarbons, sulfur hexafluoride, and filters for sulfur analysis. SF_6 and the fluorocarbon tracer will be analyzed by standard gas chromatography under controlled conditions. Filter samples derived from filter pack measurements will be processed according to procedures described by Forrest and Newman (1973). The techniques described use an isotope ratio mass spectroscopy on extracts from impregnated cellulose filters to determine isotope ratios for SO_2 and standard techniques for total SO_2 and aerosol sulfates from acid washed quartz filters.

5.2 Deposition Experiments

The second element of the deposition experiments will be determination of dry deposition velocities over scales more comparable to that of regional models and assessments. The experiments have two components: measurements by aircraft of ozone deposition by eddy correlation techniques and deposition measurements at a pair of fixed sites. Measurements of deposition at the fixed sites will be analyzed to provide a relationship to relate aircraft ozone eddy correlation measurements to the fluxes of other pollutants. This technique assumes that the ratio of pollutant to ozone fluxes at the fixed sites is representative of the ratios experienced in aircraft sampling.

5.2.1 Aircraft Measurements

Aircraft measurements are proposed to provide flux estimates for ozone and concentration measurements of sulfur and nitrogen oxides. The flux measurements will be made using the techniques described by Lenschow et al. (1980) involving eddy correlations of concentrations and vertical velocity. Fast response instrumentation allows flux estimates for averaging times on the order of minutes which will allow flux calculations for areas with dimensions of approximately 10 km. To complete the flux calculations for sulfur dioxide and other pollutants, equal ratios of boundary layer fluxes for ozone and the gases under study will be assumed for fixed sites and aircraft measurements.

The variations in budget between ozone and other pollutants observed by the surface deposition stations will also be used as a means of estimating deposition rates.

The aircraft sampling program will be performed in intensive periods within each season of the year and over the surface and vegetation types expected to influence deposition in the Northeast. The main advantage of the aircraft technique is that it provides estimates for a broad range of large scale deposition conditions. For example, deposition velocities determined over homogeneous surfaces of individual crops may not provide sufficient information on larger areas of farmland which may include the crops planted on individual fields in rolling hills and separated by trees.

The measurements to be obtained by aircraft sampling consist of vertical wind velocity, temperature, and concentrations of ozone, SO_2 and NO_x. Existing instruments have adequate response characteristics to measure velocity, temperature, and ozone concentrations. Equipment should be developed to measure SO_2 and NO_x with adequate response to insure that the eddy correlation technique can be employed.

The spatially averaged aircraft eddy correlation fluxes will be compared to ground level measurements of eddy correlation fluxes and vertical profiles of concentration, wind speed, temperature, and moisture described below.

5.2.2 Deposition Measurement Sites

The primary purpose for fixed site deposition measurements is to provide the relationships expected between fluxes of ozone and other pollutants. Since the technology of dry deposition measurements is of research rather than operational grade, the relationships between pollutant fluxes may best be found by duplicate measures at a small number of well instrumented sites. The deposition sites identified in this plan are intended to provide duplicate measurements of deposition to take advantage of the reliability of different methods under the conditions for which they perform most reasonably and to improve data precision.

The essential measurements will be eddy correlation estimates for ozone NO_x and SO_2 with vertical velocity, temperature and moisture to provide relationships to compare to aircraft data. The deposition measurement sites will be located at sites selected from the aerometric monitoring network illustrated in Figure 4-3. The sites will include real time instrumentation for other gaseous pollutants as well as measurements of some free radicals and peroxide. The latter measurements may be generally thought of as measurements leading to process descriptions but at these sites they provide a base for characterizing episodes in the development of statistics for source/receptor relationships. For example, free radical measurements can provide an indication of the oxidizing potential of the atmosphere which will in turn determine if deposition/concentration relationships can be extrapolated.

Location of the primary surface deposition sites will be determined on the basis of surface vegetation and its uniformity and on the location of other intensive field studies on the routine monitoring grid. It is desirable to monitor deposition in an area with existing monitoring data such as within the fine grid selection for the Adirondack Region and during other field monitoring periods associated with the reactive tracer experiments. Tentative sites are wooded rolling hill areas of the Adirondack foothills and farm areas in western New York.

The ground level stations used for eddy correlation flux measurements will have fast response temperature, moisture and vertical velocity sensors and instruments modified to measure O_3, NO_x, and SO_2 at adequate response times. One modification for a sulfur analyzer was described by Hicks, Weseley, Durham, and Brown (1982). These measurements will be made at heights 3 to 5 meters above local vegetation.

Vertical profiles of all of the variables listed above will be obtained to heights 50 meters above local vegetation. The vertical profiles will provide a redundant method to estimate surface layer deposition.

5.3 Local Emissions Modulation Experiments

Modulation of source emissions in space and/or time provides a technically attractive method for studying the effects of emissions changes and source attribution by direct measurement of the resultant concentration and deposition changes. The participants of the EPA sponsored design workshop identified source modulation as a desirable technique to pursue, but on a regional scale it appeared to be infeasible. For a source modulation experiment to succeed, the signal generated by the modulation must be large enough to be detectable over background by available measurement techniques. The regional source modulation concept requires generation of a signal by very large and widespread changes in emissions. This is extremely difficult to achieve due to excessive costs and the limited capability of transferring power among electrical systems. Source modulation on a smaller scale may be more feasible and is considered as a component of the combined experiment. The Adirondack grid provides locations for measurements over a smaller scale and will require a substantially smaller total oscillation to produce a detectable signal.

Some details of a local source modulation experiment have been considered and investigations to determine the feasibility of such experiments are reported in Section 8.3. The feasibility revolves around a number of questions:

- Is the Adirondack receptor area the best location for a source modulation experiment? Preliminary investigations of the emissions sources in the area indicate that the utility sources in western New York are somewhat disperse, and emissions from any single source are not particularly large. Model simulations confirm this observation and indicate that a modulation of these sources may not be detectable.

- Is there sufficient capability in local utility networks to allow substitution power from other networks during modulation experiments at reasonable costs? On the surface, the western New York utilities appear well suited in terms of interconnects with other systems and generation by nuclear and hydroelectric sources, but a complete assessment is needed.

- What are modulation requirements? Modulation assessments require a determination of the necessary size of the emissions reduction area, the magnitude of reductions, and the frequency of emissions modulations. The final emissions design must also establish the method by which the modulated emissions cases will be compared to normal concentration and deposition patterns.

It is expected that for a study extending for at most one year, the experimental design will require a relatively short term oscillation approach rather than a comparison of long term statistics.

These questions are currently being evaluated to determine if the source modulation experiments should be included in the combined experiment. If the tests are feasible, they will provide invaluable information on the contribution of local sources to deposition events. The design that was examined during the assessment of uncertainty is outlined below.

One method to determine the impact of a specific source or source area on acidic deposition is by modulation of the source. Modulation entails altering the emission rate in a regular pattern as illustrated in Figure 5-2. Deposition and air concentration data are analyzed for a sequential signal in phase with the emissions modulation.

This experiment must be conducted in conjunction with a tracer release at the source selected for change. Thus, following the dispersing pattern of the tracer downwind will identify the receptor sites most likely to experience

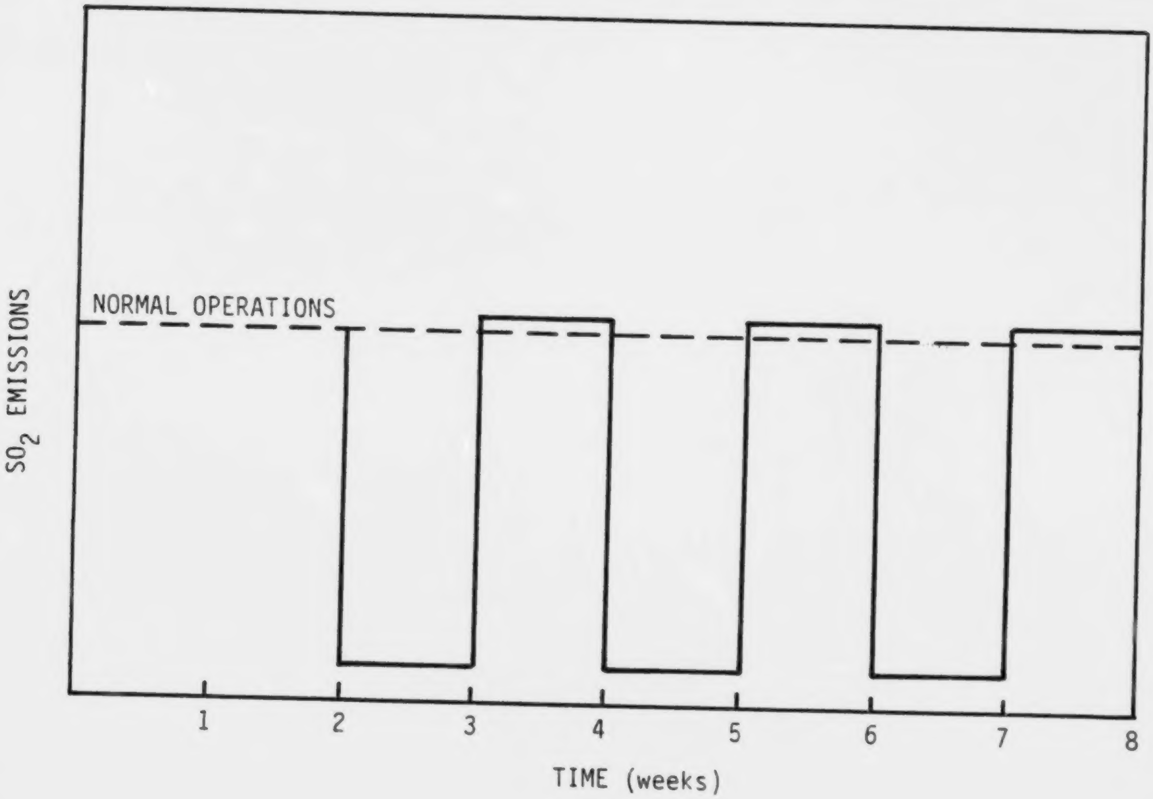


Figure 5-2. Suggested emission modification protocol for local source modulation experiment.

deposition changes associated with emission changes. To further assist in isolating the signals from selected sources at selected receptors, the deposition and ambient concentration measurements may be segregated by geographic orientation and incident wind direction, as suggested by Figure 5-3. Segregation by wind direction will isolate the effects of the source change over the receptors' field, but the presence or absence of tracer material will clearly indicate the area of influence of the modulated sources. Figure 5-2 graphically presents a suggested SO_2 emission modification protocol. The short-term SO_2 emission reduction period, when followed by a short-term normal SO_2 emission period, will allow pre-test emissions to be removed from the sampling region, after which the influence of the moduled source will predominate. The result will be a large incremental difference in SO_2 emissions for the local area. The emission modification will be subject to certain practical constraints such as costs and the need to ensure uninterrupted electric power.

The primary goal of the source modulation experiment is to test the hypothesis that SO_2 (or NO_x) emission reductions result in corresponding proportional reductions in atmospheric sulfur oxides, particularly sulfates, under typical summer and winter weather conditions. The validity of this hypothesis can be tested using a two-fold complementary approach to data analysis and interpretation:

- Direct comparison of measurements at several locations during similar meteorological periods with and without emission changes.
- Comparison of the distribution of differences between measurements and air quality model calculations with and without emission changes.

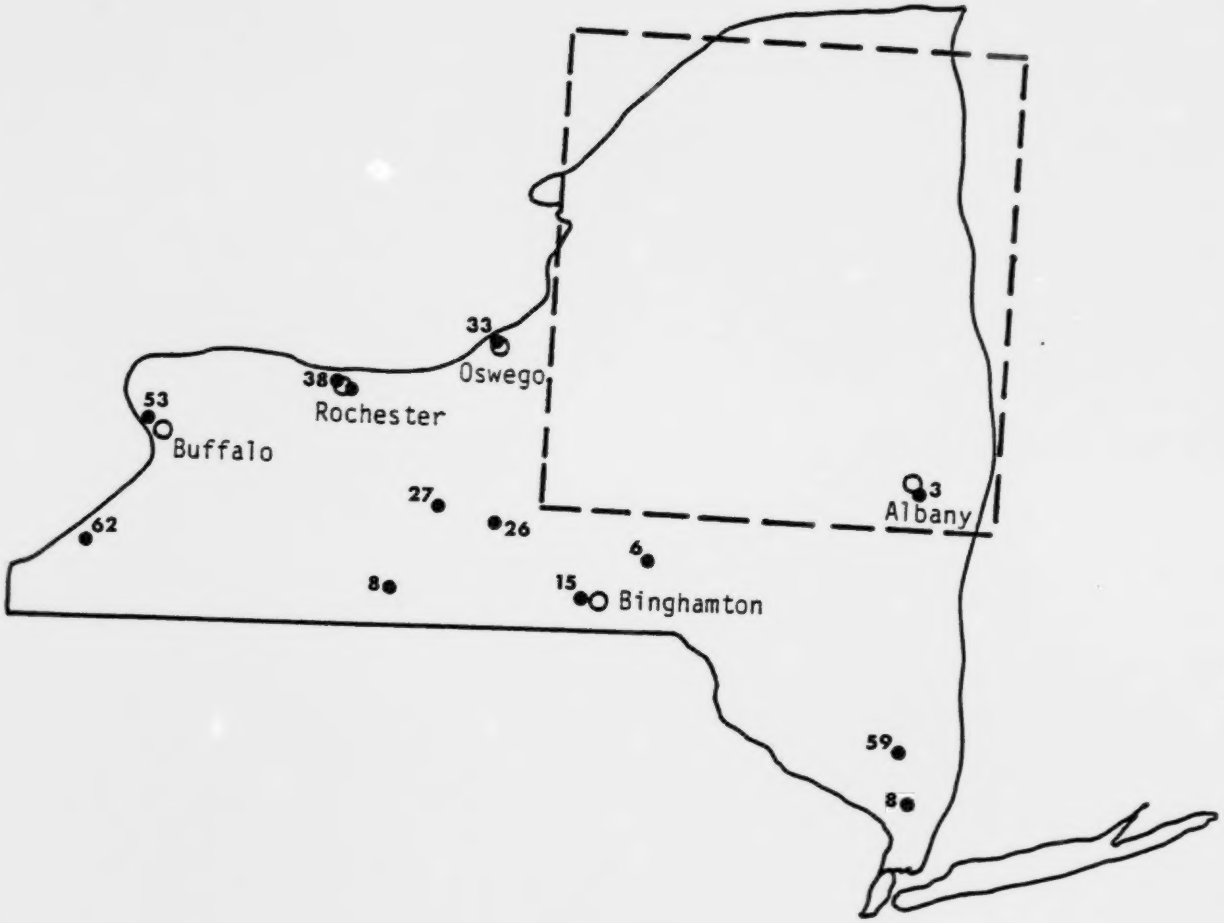

33
Oswego
38
Rochester
53
Buffalo
62
27
26
8
15
Binghamton
6
3
Albany
59
8

Figure 5-3. Distribution of New York utility sources around fine grid receptor region. Emissions of sulfur dioxide for 1982 are indicated (tons/year).

The first method involves comparisons of sulfur oxide levels among receptor stations identified by tracer concentrations as being influenced. The second method involves application of deterministic air quality models to estimate sulfur oxide behavior during the emission change program. The model calculations will estimate event ambient concentrations and wet deposition of sulfate with precision and accuracy that is based on a grouped station comparison. In similar meteorological situations, the distribution of differences between model estimates and observations is assumed to remain roughly the same. Thus, the observed shift in the mean difference can be used to determine the probable effect of emission changes. A preliminary model test was performed as part of the uncertainty examination (Section 8.3). Results of the test were not favorable for incorporation of source modulation into the program. For the case studied, the modulation of power plants near the Adirondack receptor area was not sufficient to guarantee detectability. Source modulation in a more isolated location might provide better results.

Of major concern in interpreting results from this type of experiment is the extrapolation of the data (taken over two one-month periods) to much longer periods, for example, of five to ten years' duration, the time scale over which potential acid rain mitigation benefits might occur. The extrapolation will rely on the high probability that typical meteorological events will occur during the test periods, on a cycle of approximately one week. By obtaining a cross-over from polluted to clean-air events during this cycle, sufficient data will be obtained to extrapolate to similar baseline conditions over seasonal periods. The extrapolation over a long period of time will rely on the longer term results of the full program and the assumption that air mass classification can be applied.

The short term modulation experiment cannot be done without recording the meteorology during the experimental periods and accounting for the effects of the differences between the weather during the experimental periods and the weather expected from climatology. If air mass stratification is workable, a few cases of emissions changes on representative days will yield an estimate of long term effects without a costly emission change program.

SECTION 6

ROUTINE MONITORING AND SUPPORT DATA COLLECTION

The third element of the combined experiment is a routine monitoring and support data collection effort designed to continuously monitor chemical patterns and collect emissions, meteorological and deposition data from parallel programs. These tasks will support the program in the following ways:

1. They will provide a data base for evaluation of regional acid deposition models.
2. They will provide information to characterize the variability of acidic species and precursors and infer the causes of this variability based on changes in meteorological or emissions patterns.
3. They will provide wind and pollutant concentration data to aid in the determination of transport trajectories (Section 4.0).
4. In the analysis, they will provide an input data base for interpretive modeling.
5. They will provide a historical perspective on experimental events by allowing comparisons to results of previous programs (e.g. SURE).
6. Data collected in this component will be used in a qualitative assessment of the transmittance approach proposed in Section 3.0.
7. The tasks will provide limited data for chemical transformation and oxides of nitrogen analysis.

The monitoring program is similar in concept to the EPRI SURE program but with some important distinctions. The SURE program was designated primarily to study the formation and fate of atmospheric sulfate concentrations resulting from distant emissions sources. The original impetus of SURE was the health concern related to fine acidic particles in air, but data collected have been very useful in acidic deposition studies, particularly for model evaluation. The information available from such a program can be greatly expanded by duplicating some major aspects of the experiment and adding measurements of oxides of nitrogen and more importantly concurrent precipitation chemistry. The sections which follow describe measured parameters and sampling times for the monitoring network.

The support data collection effort is difficult to define because of uncertainties in the future of numerous proposed research and monitoring programs by EPA and other agencies. This section will describe data collection requirements from support programs. Appendix A is provided to identify some supplementary data sources and studies in the categories of emissions data, precipitation chemistry data, land use and dry deposition data and major proposed research studies. The appendix also includes a description of the EPA Acid Deposition Modeling Project which will develop research and engineering models which will be evaluated using the COMPEX data base.

6.1 Routine Monitoring

6.1.1 Sampling Resolution and Locations

The long range tracer component of the study shares the network design with the routine monitoring component. Siting of stations is proposed to coincide with some previous and current air and precipitation monitoring sites used in regional monitoring programs such as SURE. The advantages of these sites over a uniform grid are avoiding difficulties in placing sites in a uniform distribution and, more importantly, providing a historical record with which results of COMPEX can be studied and analyzed to determine their climatologically representativeness. Figure 4-3 shows a collection of sites from the SURE, APIOS, CAPMoN, and the MAP3S programs which have potential for use in the study. Sites from other programs such as the National Trends Network (NTN) will also be good candidates. NTN samplers can be operated on an event rather than a weekly basis.

Prior to conducting the monitoring program for this study, siting review and site selection will be required. Some siting criteria are listed in Section 6.1.2. In addition, the review will select sites on the basis of experience gained in previous studies, by considering possible overlaps in siting in different networks, and by locating sites in areas of sparce coverage. Sites located in the fine grid network in northern New York State will also be placed by this final siting analysis.

The routine monitoring network will also include meteorological data collection by an upper air network with the current National Weather Service network as its core. Figure 6-1 shows and the existing rawinsonde stations in the study area operated by the National Weather Service. The combined experiment will require rawinsonde profiling of winds, temperature, and humidity from these sites four times per day during the experimental period. In addition, it is proposed that approximately nine additional sites be added to provide more uniform observations of the wind, temperature, and moisture fields. Some of the added sites are provided as support for the mass balance calculations and are located on the fine mesh grid. Data will be collected at three hour intervals at these fine mesh grid sites during experiments. Rawinsonde data will be supplemented by forecast model outputs to provide data for meteorological fields.

6.1.2 Siting Guidelines

It is proposed that some of the routine monitoring sites will be located at former EPRI Sulfate Regional Experiment (SURE) locations. The SURE Program monitored sulfate and sulfate precursor concentrations at 54 monitoring locations from August 1977 to October 1978. The Eastern Regional Air Quality Studies (ERAQS) continued the monitoring program at nine of the stations until December 1979. The data base compiled by the SURE/ERAQS program has been

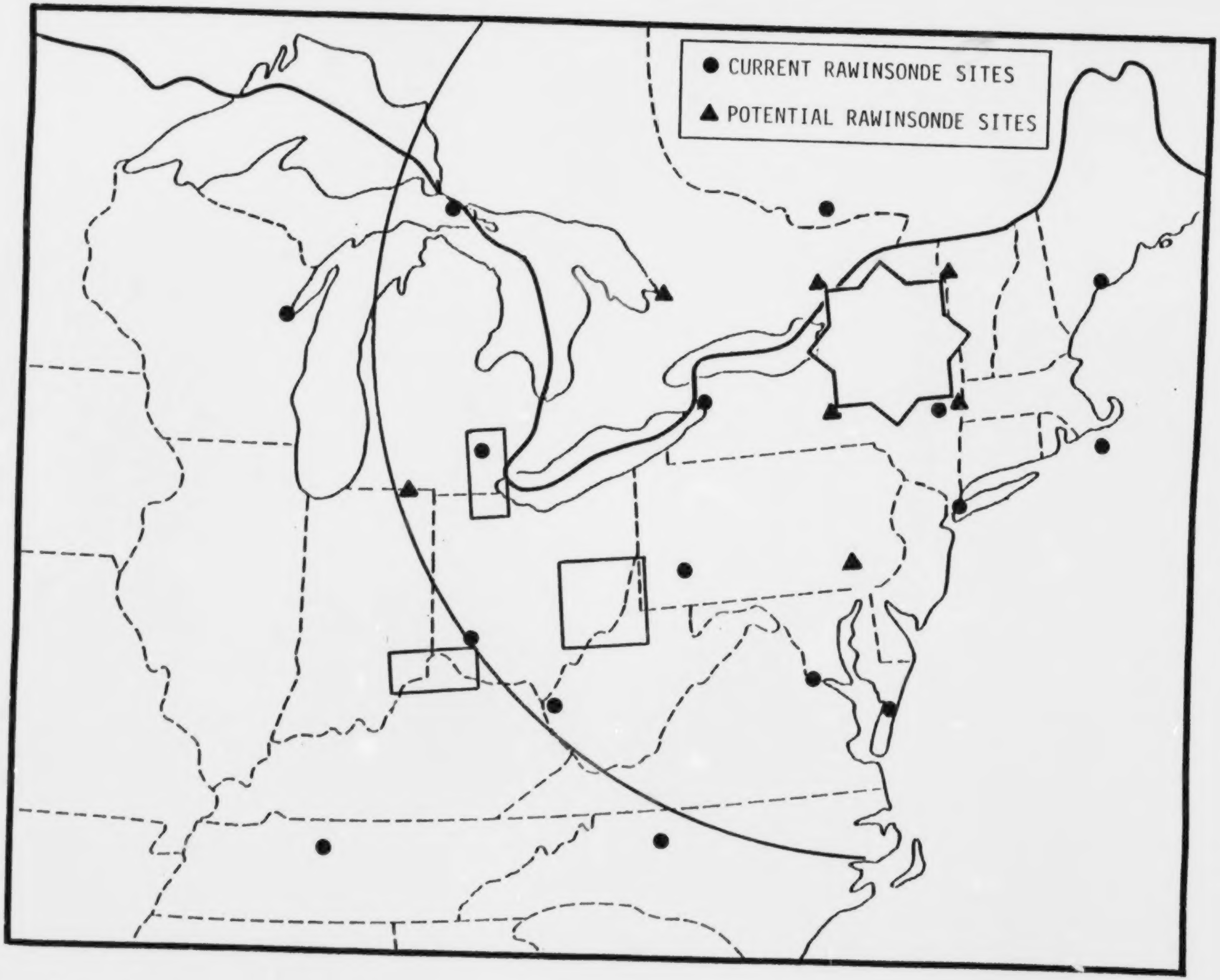

● CURRENT RAWINSONDE SITES
▲ POTENTIAL RAWINSONDE SITES

Figure 6-1. Existing and proposed rawinsonde sites for use in the combined experiment.

widely used for acid deposition studies and the program provides some guidance on siting for regional programs. Use of the same sites employed by SURE/ERAQS will permit the program to compare its data with an established data set to investigate the representativeness of the sampling period and to investigate any significant changes in observed concentrations that occurred in the time elapsed between the two field studies.

The data gathered by the routine monitoring network will be representative of concentrations on a regional scale and local influences to concentrations should be avoided. Sampler siting will consider the potential for local sources and local flow regimes to influence or provide anamolous monitored concentration data.

As a practical criterion, it is useful to define "regional scale" in terms of the modeling grid scale of 80 km. Where ever possible, the monitoring stations will be located at least one-half grid space (40 km) away from significant anthropogenic sources. Under most meteorological conditions, this criterion should minimize the contribution of individual sources to the observed concentrations.

Terrain induced local, sub-grid scale wind patterns may also result in anomalous concentration measurements that may be difficult to interpret in conjunction with the overall monitoring network concentration pattern. For example, valley drainage flow may become established that are not related to the regional transport wind direction. Tracer concentration data from the CAPTEX program showed lags of concentrations for material being transported through the CAPTEX area. This effect may have been a terrain induced phenomenon. Individual station locations should be reviewed for potential local wind anamolies.

Sampling sites should also be reviewed with the following additional criteria in mind:

1. Local sources of contamination should be avoided.
2. Flow obstructions should be avoided.
3. The sites should be accessible under all weather conditions and at all times (sites without ready access are likely to have low data, capture rates).
4. Reliable, commercial power is desirable at all sites. Batteries as the primary power supply should only be used as a "last resort."
5. The land use of the area surrounding the sites should not change during the monitoring programs.

It may not be possible to meet all of these criteria at all of the monitoring sites, however the criteria will serve as guidelines and should be used where feasible. Candidate sites where the criteria cannot be met will be carefully reviewed and alternative and supplementary monitoring locations will be considered. Exceptions to the criteria at the actual monitoring locations should be documented on a site-by-site basis to assist data analysts in understanding anomalous monitoring results.

6.1.3 Station Configuration

Two types of routine monitoring stations will be deployed for the experimental period. Routine monitoring will sample rain water chemistry and the concentrations of acidic gaseous and particulate species. Two special stations will be deployed that measure the oxidizing potential of the atmosphere, plus all of the species monitored at the standard stations.

Table 6-1 presents a list of the concentration data to be collected at the routine monitoring stations. Hi-vol/filter pack techniques will be used to collect concentration data for HNO_3, aerosol nitrates, SO_2, and $SO_4^=$.

Filter packs are convenient, and are the most sensitive means available for routinely assaying these species at low ambient concentration levels. The oxidizing potential of the atmosphere will be assessed at two special sites by measuring O_3, H_2O_2, and free radical concentrations. One of these sites will be within the fine mesh grid area of northern New York State, the other site will be on the coarse grid in the Ohio Valley source region.

The filter packs used to measure the concentrations of acidic gaseous and particles will contain three types of filters. These are acid washed quartz, carbonate impregnated cellulose, and nylon filters. The quartz filters collect sulfate and nitrate particles. The cellulose filters will collect gaseous sulfur dioxide and nylon filters collect nitric acid samples. The filter packs will be exposed in standard Hi-Vol samplers with a flow rate of 50 ft^3/min for six-hour periods. Concentration analyses will be done via extraction, and the expected limit of detection is on the order ten parts per trillion (ppt), or less for all species. Anticipated concentrations at all locations are expected to be higher than the ten ppt level.

Measurements for establishing the general oxidizing potential of the atmosphere have been identified as important to adequately stratify data for developing source/receptor relationships. Since the program does not stress the study of the complex chemical transformations, these data will provide a means of isolating the effects of environments with potentially high transformation rates. Methods for H_2O_2 and free radical measurements cannot be considered operational for routine monitoring and indeed questions arise as to whether all interferences have been identified. As a result, methods for measurement should be specified later in the operational plan. The strong potential exists to combine these measurements with those of the eddy correlation/ratio dry deposition experiments (Section 5.2.2).

TABLE 6-1

CONCENTRATION DATA TO BE GATHERED AT THE ROUTINE MONITORING STATIONS

Gaseous/Particulate Species Measurements	Precipitation Chemistry Measurements
SO_2	H^+(free)
$SO_4^=$	Conductivity
HNO_3	$SO_3^=$
NO_3^-	$SO_4^=$
Inert Tracers	NO_2^-
O_3	NO_3^-
H_2O_2*	Cl_3^-
Free Radicals*	PO_4^{3-}
NO_x*	NH_4^+
	Na^+
	Ca^{++}
	Mg^{++}
	Sample Weight
	Amount

*(Measured at two special stations only)

Precipitation samples will be gathered at each routine site in a "wet-only" collectors. Sample collection buckets will be constructed of a inert material that will not chemically react with the samples. The collectors will be located at ground level or on platforms, if necessary, to keep them above the maximum expected snow depth.

Samples will be tested for pH and conductivity, labeled and weighed in the field, and then will be refrigerated at 4°C pending shipment to the laboratory for ion analysis. Sample shipping will via the U.S. Postal Service or commercial carriers. Samples will be collected for each 24-hours during which precipitation occurred. A recording rain guage will be deployed at each site to record the duration and amount of precipitation during each event. Wind screens will be used around both the precipitation chemistry collector and the recording rain guage.

The stations will require adequate security and temperature controlled instrument shelter/workspace. Sufficient area must be isolated, so that the precipitation samplers can be located an adequate distance from fences. Shelter for the O_3, and conductivity/pH meters, etc., and storage for supplies such as buckets, labels, jars, etc., will be provided in a temperature controlled shed. These instrument sheds must be both heated and air conditioned to maintain equipment within the manufactures' temperature specifications. The instrument sheds must be secured with adequate locks and be located inside a security fence. Provisions for dealing with site accessibility in remote areas and during adverse conditions should also be considered.

6.2 Support Data Collection

In addition to measurements collected at the routine monitoring sites, a number of other data types will be needed to complete the analyses and meet the projects objectives. These data will be obtained through cooperative agreements, or be routinely available information sources and will be entered into the project data archive (Section 7.3).

6.2.1 Emissions Inventories

Detailed emissions data for the species of interest must be available for the analyses to be meaningful. Both the average emissions and the time history of the variability of the emissions for the major point and area sources of sulfur and nitrogen oxides must be collected. Statistical models for area sources (e.g. automobile traffic, residential, commercial etc.) will be used to estimate the emissions of small sources. For major industrial and utility sources, emission data must be available or calculated based on load. These data should be compiled for each 3-hour period during the monitoring program. For source areas tagged by tracers, the emissions should be derived based on actual operating conditions for experimental periods. For other sources, more coarse data could possibly be used. Emissions data must be available not only for the final data analyses, but also to facilitate a preliminary assessment of the effectiveness of the experimental design. Emissions data for the preliminary assessment need not be as complete as that later for the final analysis, but should include time-of-day adjusted area source terms and estimates of actual emissions from major point sources in the tracer emission areas. Emissions data from the tracer release regions should be available for the preliminary assessments within thirty days of the end of each monitoring month.

The complete emissions inventory for the entire experimental region must be available for the final data analysis. The final emissions data base will be similar in content to the Canadian LRTAP Program and the U.S. NAPAP emissions data bases, and should contain the following information; temporal resolution on the order of 3-hours; area source spatial resolution of at least 80 x 80 km, information on major points sources including actual (or calculated) emissions, stack height, diameter gas exit velocity, temperature, and location. Work in progress for EPRI (Heisler, 1984) will permit the apportionment of area source emissions on a 3-hour basis with reasonable confidence. Because utility boilers alone account for about two-thirds of the total anthropogenic SO_x emissions in the United States, actual or calculated emissions for these major point sources must be obtained for the experimental period.

6.2.2 Meteorological Data

The project will acquire most of its meteorological data from the National Weather Service's (NWS) routine observing program. Table 6-2 presents the types of meteorological data to be included in the project data base. Surface, satellite and radar data will be archived for the entire region, for each hour of the monitoring program. These data are available from NWS. Sixteen NWS rawinsonde stations will be supplemented by nine sites operated by the project. NWS rawinsondes are routinely released at 00 and 12 Greenwich Mean Time (GMT), however during the experimental period, additional rawinsonde will be released at 06 and 18 GMT for the rawinsonde stations in the coarse grid region. Sites in the fine grid will release rawinsondes every 3 hours throughout the experiments.

6.2.3 Deposition Data

Wet deposition data will be available from the project sites and from five precipitation chemistry networks expected to be in operation during the experimental period. The Multi-State Atmospheric Power Production Pollution

TABLE 6-2

METEOROLOGICAL DATA TYPES TO BE COLLECTED

- Rawinsonde profile
  - Temperature (mixing depths)
  - Humidity
  - Pressure
  - Wind speed
  - Wind direction

- Radar
  - Precipitation location
  - Duration
  - Intensity

- Satellite
  - Cloud cover
  - Cloud top temperatures

NWS surface data
Sky cover
Wind speed
Wind direction
Temperature
Visibility
Significant weather

Dew-point temperature
Cloud type
Cloud height
Precipitation amount

Barometric pressure
Barometer trend

Study (MAP3S), the Utility Acid Precipitation Study Program (UAPSP), the Acidic Precipitation in Ontario Study (APIOS), the Canadian Air and Precipitation Monitoring Network (CAPMoN), and the National Trends Network (NTN) will provide supplemental wet deposition data to the project. These are discussed in Appendix A.

No widely accepted methods currently exist for directly measuring the dry deposition rate. NAPAP is sponsoring a research program with the goal of developing dry deposition monitoring techniques (Interagency Task Force on Acid Precipitation, 1984). Two approaches are currently being investigated. The first method involves measurement of ambient concentrations and the application of an assumed deposition velocity to calculate the dry deposition rate. The second approach utilizes micrometeorological techniques (e.g., eddy correlation, simularity theory) to measure the fluxes. This approach requires the development of new, very fast response pollutant sensors. If a suitable technique is developed, NAPAP plans to deploy the measurement equipment at selected NTN sites. If these dry deposition data are available, they will be acquired for the project period.

SECTION 7

EXPERIMENTAL MANAGEMENT AND CONTROL

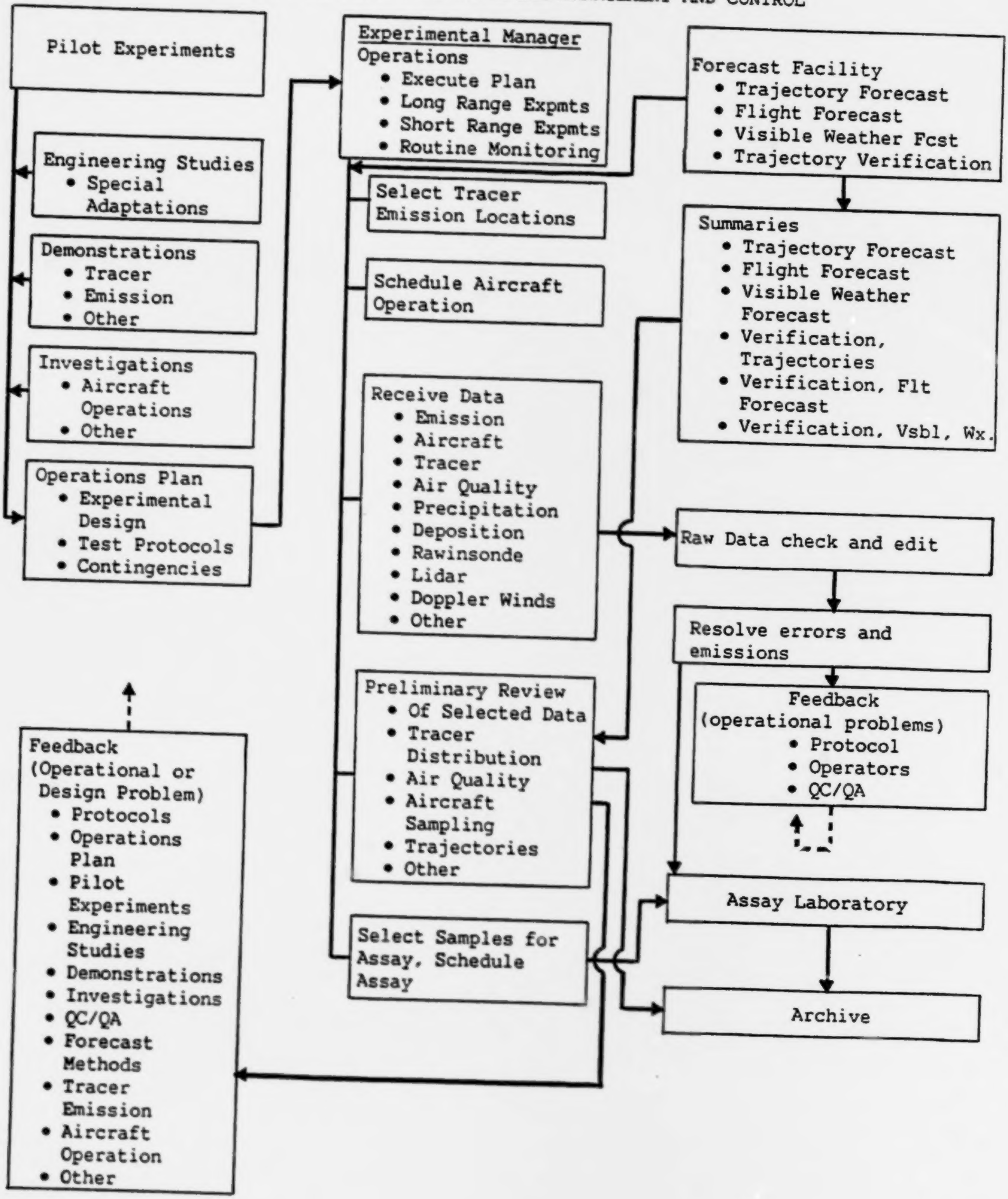
The COMPEX program design requires detailed planning and an active management and control effort. The major management/control functions of the COMPEX program are shown in Figure 7-1. The field measurements portion of the COMPEX program will be carried out in the form of a series of interrelated measurement projects. Some of the measurement projects will not be dependent upon the daily meteorological situation and they can be carried out on a continuing schedule. This will be specified in an operational plan at the outset of program. Other measurements will be critically dependent upon the meteorological situation and on forecast conditions for the duration of each measurement episode.

These latter measurement projects will also be described by the operating plan but will be controlled by an Experimental Manager for critical decisions such as locations of tracer emission points, aircraft flight patterns, and other aspects determined by ambient meteorological conditions. The Experimental Manager will also manage the day-to-day functions, and monitor the progress of all the field measurement functions including those that are carried out on a continuing schedule. He will review the data that are generated in order to assure that operational plan is being followed and to assure that if unexpected occurrences are experienced, proper adjustments can be made in either the operational approaches and/or the measurement protocols.

The long range experiments, short range experiments and the routine air quality monitoring program will all be carried out concurrently and the Experimental Manager will direct management of all programs through a control center which coordinates communications with a Tracer Emission Team, an Aircraft Operation Team, a Data Assay Laboratory, individual Field Measurement Teams and a supporting Meteorological Forecast Facility. The Meteorological Forecast operation will provide forecasts which will be used by the

FIGURE 7-1

FLOW DIAGRAM - EXPERIMENTAL MANAGEMENT AND CONTROL


Pilot Experiments
Engineering Studies
• Special Adaptations
Demonstrations
• Tracer
• Emission
• Other
Investigations
• Aircraft Operations
• Other
Operations Plan
• Experimental Design
• Test Protocols
• Contingencies
Feedback (Operational or Design Problem)
• Protocols
• Operations Plan
• Pilot Experiments
• Engineering Studies
• Demonstrations
• Investigations
• QC/QA
• Forecast Methods
• Tracer Emission
• Aircraft Operation
• Other
Experimental Manager
Operations
• Execute Plan
• Long Range Expmts
• Short Range Expmts
• Routine Monitoring
Select Tracer Emission Locations
Schedule Aircraft Operation
Receive Data
• Emission
• Aircraft
• Tracer
• Air Quality
• Precipitation
• Deposition
• Rawinsonde
• Lidar
• Doppler Winds
• Other
Preliminary Review
• Of Selected Data
• Tracer Distribution
• Air Quality
• Aircraft Sampling
• Trajectories
• Other
Select Samples for Assay, Schedule Assay
Forecast Facility
• Trajectory Forecast
• Flight Forecast
• Visible Weather Fcst
• Trajectory Verification
Summaries
• Trajectory Forecast
• Flight Forecast
• Visible Weather Forecast
• Verification, Trajectories
• Verification, Flt Forecast
• Verification, Vsbl, Wx.
Raw Data check and edit
Resolve errors and emissions
Feedback (operational problems)
• Protocol
• Operators
• QC/QA
Assay Laboratory
Archive

Experimental Manager as a basis for selecting tracer release locations, and scheduling aircraft operations as well as other experimental functions that are dependent upon the daily meteorological situation. The forecast operation will also provide forecast verifications which in turn will provide input to sample selection for assay scheduling and for preliminary analyses of critical field data.

The experimental management staff will routinely receive data from all the measurement tasks. These data will be reviewed for completeness and adherence of measurement and documentation practices to protocol specifications. Subsequently the data packages will be screened and selected portions will be prepared for preliminary review. The preliminary reviews will be conducted at prescribed intervals to assure that data quality needs are being satisfied and that technical findings can be reviewed and fed back to the experimental design, or plans for new measurement methods, or pilot experiments. Data that have been reviewed will then be entered into the archive.

7.1 Critical Path Analysis

7.1.1 Overview Chronological-Operational Control

In the course of designing the COMPEX experimental and the operating protocols, several existing knowledge gaps must be filled. Underdeveloped experimental and analysis methods have been identified in the form of preliminary investigations, and feasibility or demonstration pilot studies. These pilot experiments and preliminary investigations must be conducted to generate information and experimental methods as the basis for design of a full scale operational plan and operating protocols.

The identification and establishment of the scope of these preliminary works as well as their timing take the form of a critical path analysis. The critical path analysis will serve to fully identify each problem area and to identify optional approaches and methods where new technologies or new applications of existing techniques are to be pursued. The critical path through all of the pilot experiments and preliminary investigations will then provide the specifications to develop the operational plan.

The specific areas which must be pursued through preliminary investigations and pilot studies are listed below:

- Determine if the inert and reactive tracers suggested for the COMPEX experiments are detectable in all weather conditions.
- Develop tracer release scenarios to simulate the emission of precursor pollutants from the main emission source areas and represent individual sources as they may be employed in short range experimentation.
- Determine if inert tracer concentration patterns can be employed to simulate pollutant deposition patterns.
- Determine if deposition by wet and dry processes can be determined using reactive tracers.
- Determine if flux and statistical methods are workable in practice enabling use of the transmittance approach to determine source allocation.
- Develop and verify the source modulation technology appropriate for use in the short range experiments.
- Determine if dry deposition can be measured by ozone eddy correlation/ratio techniques.
- Determine if estimates of transmittance and deposition adequately reflect plume depletion and mass balance.

A critical path diagram detailing all of the above problem areas will be a component of the operational plan. An example critical path diagram is, however, presented as Figure 7-2 in order to illustrate the type of preliminary investigations needed, the potential alternate approaches that may be employed, and to illustrate the manner in which this preliminary work will provide input for the operational design.

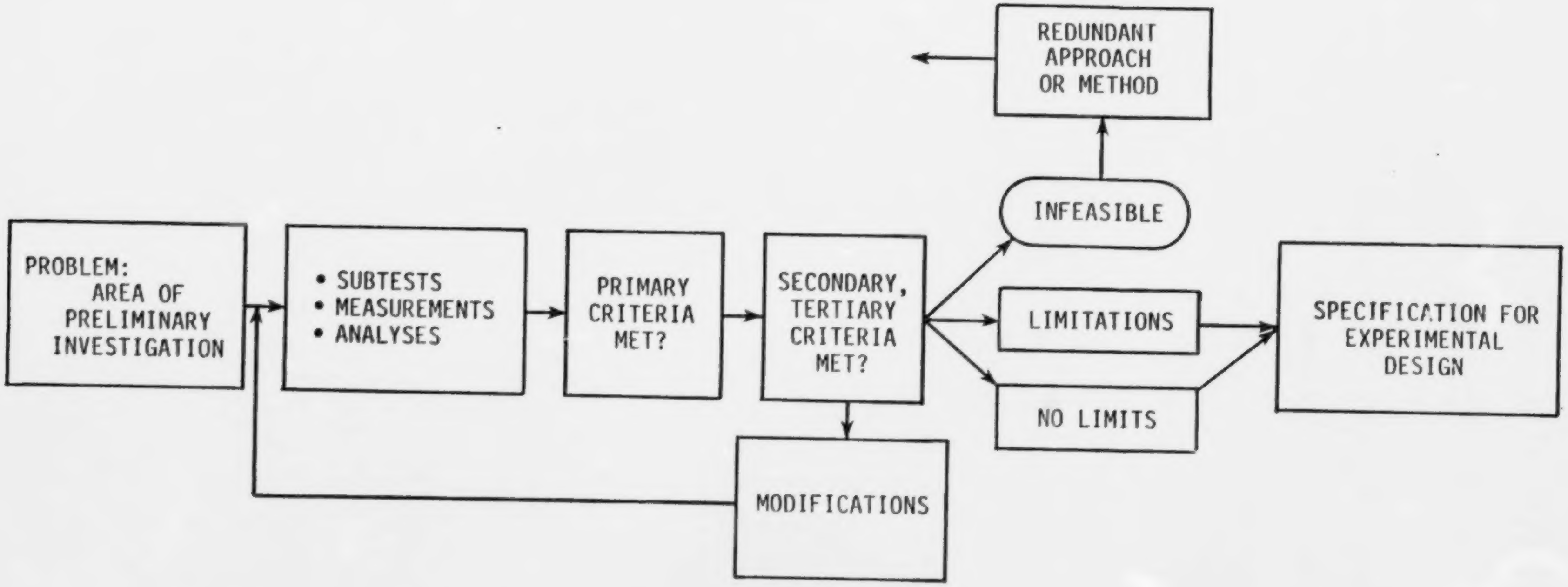

PROBLEM:
AREA OF
PRELIMINARY
INVESTIGATION
• SUBTESTS
• MEASUREMENTS
• ANALYSES
PRIMARY
CRITERIA
MET?
SECONDARY,
TERTIARY
CRITERIA
MET?
MODIFICATIONS
INFEASIBLE
REDUNDANT
APPROACH
OR METHOD
LIMITATIONS
NO LIMITS
SPECIFICATION FOR
EXPERIMENTAL
DESIGN

Figure 7-2. Conceptual Critical Path Diagram

7.1.2 Schedule

The overall program will begin with pilot experiments, engineering studies, demonstrations or special investigations as necessary to generate information about the experimental methods and techniques for the full scale experimental program. Preliminary work is directed toward development of an operational plan. Although the time period for these preliminary efforts cannot now be specified, it is expected that the major portion will be completed during the first year of the program while the experimental methods as the measurement full scale experimental protocols are being designed.

When the measurement protocols and the operational plan have been completed, the full scale field measurement program will be initiated. The long range, the short range, and the routine measurement programs will be conducted over a one-year period.

The major feature of the experimental schedule will be releases of two atmospheric tracers for a twenty-four hour period every third day. Ground level tracer sampling will be carried out on a continuous schedule with one sample every six hours, because of the large distances involved (1000 km), and large tracer plume expansion. Aircraft sampling will generate samples of both tracer and pollutants in the receptor area, therefore will be dependent on the presence of a tracer plume at the fine mesh receptor grid. All other observations will be carried out on a continuous schedule for the duration of the experiments.

7.2 Critical Elements of Program Control

The experimental management and control will be carried out by the Experimental Manager and his supporting staff. The support staff will consist of two groups. The first is a Meteorological Forecast Group and the second is a Data Review Group.

The Forecasting Group will provide routine forecasts of meteorological factors that are of specific concern for program control. The primary tasks of the forecast facility will be 1) to provide forecasts of atmospheric trajectories to identify episodes where the pollutant source regions are expected to influence the receptor area, 2) to provide forecasts of flight weather in the same region for the sampling/sounding aircraft operation, and 3) to select data for assay and preliminary reviews of field data.

The Data Review Group will be primarily concerned with receipt of field data, review of the field data documentation, preliminary technical review of selected data and entry of all data into the archive.

The experimental management staff will perform the five functions described below. These functions are designed to provide optimum experimental operation, coordination of field efforts, continuing review of the data generated, and feedback of special findings so that experimental measurements and field methods can be modified if necessary.

7.2.1 Select Tracer Release Locations

As described in previous sections, several candidate tracer release areas will be established in areas of high precursor pollutant emissions. The specific release location, or locations, will be determined by the experimental management staff based on the forecast of atmospheric trajectories provided by the forecast group. The location of the tracer emission areas will be communicated to the tracer emission staff who will perform the tracer releases and document the specific details.

7.2.2 Schedule Aircraft Operations

Aircraft sampling will be conducted to determine material distributions and balances of both atmospheric tracers and the emitted pollutants.

The Experimental Manager will determine aircraft sampling schedules and locations for the sampling flights based on the forecast of atmospheric trajectories. Verification of the atmospheric trajectories and subsequent forecasts of new atmospheric trajectories will be used by the update and adjust the location and timing of subsequent sampling flights. The locations and times of the aircraft operations will be communicated to the flight crews.

7.2.3 Receive Data

The Data Review Group will receive all the data generated from the long range experiments, the short range experiments and the routine monitoring activity. Three major functions will be performed with the data received. The first is to cross-check the field documentation including location, time, method of observation, units, operator identification, etc., against the field protocol specifications. If differences or omissions between the actual documentation and the specification exist, these differences will be identified and logged and specific details will be fed back into the system. Field protocols or field methods can then be modified to preclude future problems. If appropriate, the quality control/quality assurance staff will be apprised to further document or initiate corrective action. A second function of the Data Review Group will be to select cases from the data received and to prepare the data for preliminary technical review. This function consists mainly of preparing plots of atmospheric tracer data, air quality data, verified atmospheric trajectories, etc., as are needed for review by the Experimental Manager. The third function of the data review group will be to enter all the data into the archive.

7.2.4 Preliminary Review of Data

Preliminary review of selected data will serve multiple purposes. First, it verifies the level of success of each individual operation. Second, it identifies data that have particular significance relative to the experimental objectives and identifies data that are of lesser interest. This will provide a basis for prioritizing data assay. Third, by reviewing portions of the data sample, it will be possible to identify those portions of the measurement programs that require further refinement or change. By this identification, a valuable feedback loop is established which can lead to modification, further development, or altered emphasis in the field protocols or the experimental methods.

The Experimental Manager will conduct the preliminary data reviews and based on the findings, initiate the appropriate feedback. The preliminary analyses will be entered into the archive.

7.2.5 Select Samples for Assay and Schedule Assay Work

Some of the measurement efforts will proceed on a regular, continuous schedule throughout the course of the experimental program. Since the atmospheric tracers will be released every third day some of the field observations will be of lesser or no concern because they will have been taken during periods between study episodes. The Experimental Manager will provide an overview of the entire operation, and with preliminary data reviews, will establish the data assay priority.

7.3 Feedback

Several references have been made to the feedback of findings to experimental design, protocol design, and to experimental methods development, etc. It is appropriate to reemphasize the importance of feedback in this type of an experimental program since although some of the experimental methods to be employed consist of well established techniques, their use in the field measurement program represents configurations not previously employed. This being the case, some monitoring or close scrutiny of methods and results is required so that modifications can be made if the newer configurations prove to be less than optimum.

An example of this need can be seen with the tracer release mechanism for the perfluorocarbon atmospheric tracers. The device has been used in the past on the CAPTEX program, however, it may require modification to assure reliable, continuous tracer releases over long periods. The modification itself appears to be a simple engineering adaptation which will be accomplished and tested as a preliminary step, but the operation of the modified device should be closely monitored during the initial field experimental period. If problems develop, feedback will allow engineering refinements to resolve those problems.

Other assessment requirements originate from application of new technology or from unusual applications of existing methods. Of particular importance will be the trajectory forecasting methodology. There exist trajectory prediction methods, however, since the atmospheric tracers along with the precursor pollutants are expected to travel for up to two days between the emission areas and the receptor area, the effects of atmospheric stratification and shear are significant. Feedback of atmospheric tracer sampling data will enable review of trajectory predictions versus sampling data. These comparisons can then be employed to refine the trajectory prediction methods, if that is necessary. Other examples of important feedback can be seen from Figure 7-1.

7.4 Pilot Experiments, Engineering Studies, Demonstrations, Investigations

Preliminary efforts are planned to develop the information needed to design the operational plan and to determine if certain methods in the design will be workable in a large scale program. These preliminary efforts can take the form of pilot or feasibility experiments, engineering studies, demonstrations or special investigations as described in the following section. In addition to staged experiments and studies, special investigations will be needed for operational planning such as determining aircraft distance separations, minimum aircraft flight altitudes during IFR conditions, or atmospheric conditions that would cause sampling aircraft to divert from a prescribed flight path.

In addition to the preliminary efforts described above, similar efforts may be needed during the course of the experimental program. This may be especially true during the early phases of the experiments. Preliminary data reviews and experience with measurement protocols will point out the need for altered or refined methods.

7.5 Data Archive

The large amount of data generated from this program will require an organized data archiving system to assure complete and easy access for analysis and quality assurance checking. The basis for such an archiving system should be a Data Base Management System (DBMS). A DBMS integrates large files into a single data base allowing multiple users to effectively and efficiently access the data. Selecting a DBMS and establishing protocols for transferring data to the system should be a priority item for COMPEX.

A DBMS has many positive attributes. First, it eliminates data redundancy in archiving and frees users from the data structures imposed by conventional file storage methods Computer data files need not be restructured for each different program that uses them and a simple data item needs to be stored only once to enable all programs to access it. The DBMS creates one pool of integrated and sharable data for a variety of users, eliminating duplication of data tracking efforts as well as reduction storage space.

Second, a DBMS is usually acquired with a number of user aids, such as a query language, a report writer, application development packages, and transaction journaling and recovery. These tools enable users and systems programmers to manipulate the data far more easily and flexibly than in the old sequential files. The DBMS requires less training, experience, and skill from its users.

Third, a DBMS allows users to instantaneously query, edit or update their data. This is another advantage over conventional systems often plagued by excessive lapse times between job submittals and receipts. Creation of a system on a DBMS tends to consolidate information, and this in turn, may ease the applicability of the system for all available future users.

EPA currently maintains three major systems for managing air information. Hourly averages of parametric air quality and meteorological data are managed by the Storage and Retrieval of Aerometric Data (SAROAD). The National Emission Data System (NEDS) tracks point source emission data. EPA's Compliance Data System (CDS) tracks non-parametric information regarding the compliance status and enforcement activities of stationary sources of air pollution. Currently, EPA is designing an integrated system to replace the existing NEDS, CDS, and SAROAD systems which may be useful to COMPEX. This is the Aerometric Information Reporting System (AIRS). EPA's current options are to develop AIRS as a DBMS, to develop AIRS as a conventional file management system, or to continue processing with their current systems.

AIRS as a DBMS is an attractive alternative. The large pool of integrated, non-redundant data would be available to the variety of users in the EPA. On-line capabilities for instantaneous data revision and updating would increase the efficiency and effectiveness of the system.

One of the data base software packages supported by EPA is ADABAS, the Adaptable Data Base System. In 1984 EPA made a commitment to ADABAS for any data base system design during this period. ADABAS is an easy DBMS to use and is designed for a large number of query applications which vary from request to request. The "loose" file structure means that data relationships are flexible and can be respecified for every query, if necessary. The weakness of this "loose" structure is that batch production jobs, doing the same job over and over again, will cost more than a tightly structured DBMS version of the same system. Applications are easily implemented, and four separate query languages are supported. If AIRS is developed as a DBMS, it should be developed using ADABAS, because of EPA's current commitment to ADABAS.

SECTION 8

DESIGN REFINEMENTS

Experimental design is a dynamic process particularly when plans include techniques and combinations of techniques which have not been proven in previous experiments. This section reviews progress to date in refining the experimental design. It also presents a description of a staged approach which formalizes procedures for further refinement and improvement of the plan.

8.1 Critical Issues

On September 18, 1984, a meeting was held in Washington to review the progress of plans developed by TRC and ERT for the COMPEX and MATEX programs. The intent of the meeting was to assess the plans and to determine similar or different elements. The main result of the meeting was a list of sensitive areas requiring further study. This list combined with comments from previous sections identify the following critical topics for the proposed experiments:

1. Integral measurements of dry deposition and precipitation - The experimental design is based primarily on a mass transmittance approach. Some components of the transmittance approach require high resolution, high precision measurements for determination of profiles, fluxes, and integral samples. Problems with these measurement objectives have been identified in the past and persist. Measurement programs have long sought to describe how point measurements represent larger fields of parameters in the presence of variability in those measurements. In the proposed transmittance plan, distributed tracer releases will simulate emissions from a large array of emissions sources. The effect of combining sources also needs to be understood.

   The transmittance approach also requires the combination of aircraft, ground and remotely sensed measurements of different sensitivities and sampling times. These will be taken over large receptor area to estimate mass distributions, balances and fluxes. Results of the measurement program for the limited area mass balance component of the study must have low enough uncertainty levels to allow differencing of flux estimates. In the approach, transmittances are applied on the large scale to pollutant transport segments between the source and the receptor area. More confidence could be placed in the approach if it was known that process or small scale variability was not so large that it would overwhelm the detectability of future measurement systems.

Another consideration in the question of integral measurements is whether representative or meaningful regional scale deposition estimates are possible. This design effort has highlighted the need to estimate deposition rates over large areas.

2. Tracer Use and Applications - The design of COMPEX requires the use of tracers in new applications. Several topics relating to tracer use have been identified:

   - Can PMCP be used as a long range tracer with the same success as PMCH?

   - Are distributed source tracer releases feasible in representing major emissions source areas?

   - Are inert tracers used for long range studies detectable in all weather conditions?

   - Can sulfur-34 be used as a reliable and detectable tracer for mesoscale studies?

   - Can dry deposition estimates be obtained by plume depletion techniques at distances which marginally satisfy method assumptions in terms of homogeneity and stationarity?

3. Estimation of Statistical Uncertainties - The estimation of uncertainties associated with the experimental design is not possible prior to the field measurement. The approach is not a direct method of determining source/receptor relationships and the effectiveness of combining components is not currently known. In some cases, it is not clear if the proposed methods will be feasible.

4. Emissions Modulation or Emission Change Hypothesis - One of the most direct methods of determining if emissions controls work is to modify emissions and to measure the resultant impacts. Variability in meteorology and limitations in measurement technology make this experiment difficult and possibly infeasible due to problems in identifying the modulation signal in deposition data. Large modulations involving emissions change over large regions of the country could potentially result in detectable levels, but the cost of large modulations is excessive. The combined experiments have a source modulation component using local sources to study impact on a nearby receptor area. Conduct of this experiment would allow an assessment of derived source/receptor relationships as well as providing an estimate of the importance of local versus long distance sources. Preliminary modeling studies showing the effects of a group of central New York utilities indicates that source modulation in the Adirondacks may not provide a sufficient concentration signal to be detected,

and the deposition signal may be even more difficult to detect. Source modulation in other remote areas with larger emissions may provided a better signal for analysis. If a proposed experiment meets these conditions, other criteria such as the availability and capacity of other power or production sources would need to be investigated further.

8.2 Staged Approach

The combined experiment program represents a very large experimental and analysis project consisting of a number of component parts of which some are untested. This indirect approach precludes an estimate of uncertainties associated with development of source/receptor relationships and, as a result, presents a risk of possible failure unless additional information is provided for a feasibility determination. Recognizing this problem, the plan was modified to incorporate a staged approach. This approach includes a series of uncertainty analyses, feasibility studies and demonstration studies which will allow a determination of whether a program task, or the program as a whole is feasible before the irrecoverable commitment of funds.

Figure 8-1 gives a brief summary of the decision making process involved in the staged approach from the planning stage through the full scale experimental program. Specifically, under the staged approach, decisions must be made on the feasibility of approaches, and experimental and analysis procedures to assure success of the project. Feasibility determination and design refinements are necessary and these will be made on the basis of uncertainty studies, feasibility experiments, and demonstration experiments. The final determinations of feasibility or prospects for success are not shown in the figure. It is an initial analysis of experimental data early in the experimental program.

Uncertainty studies for feasibility determinations and design guidance were performed concurrently with the preparation of this design and some results have been incorporated. The studies which review experimental data

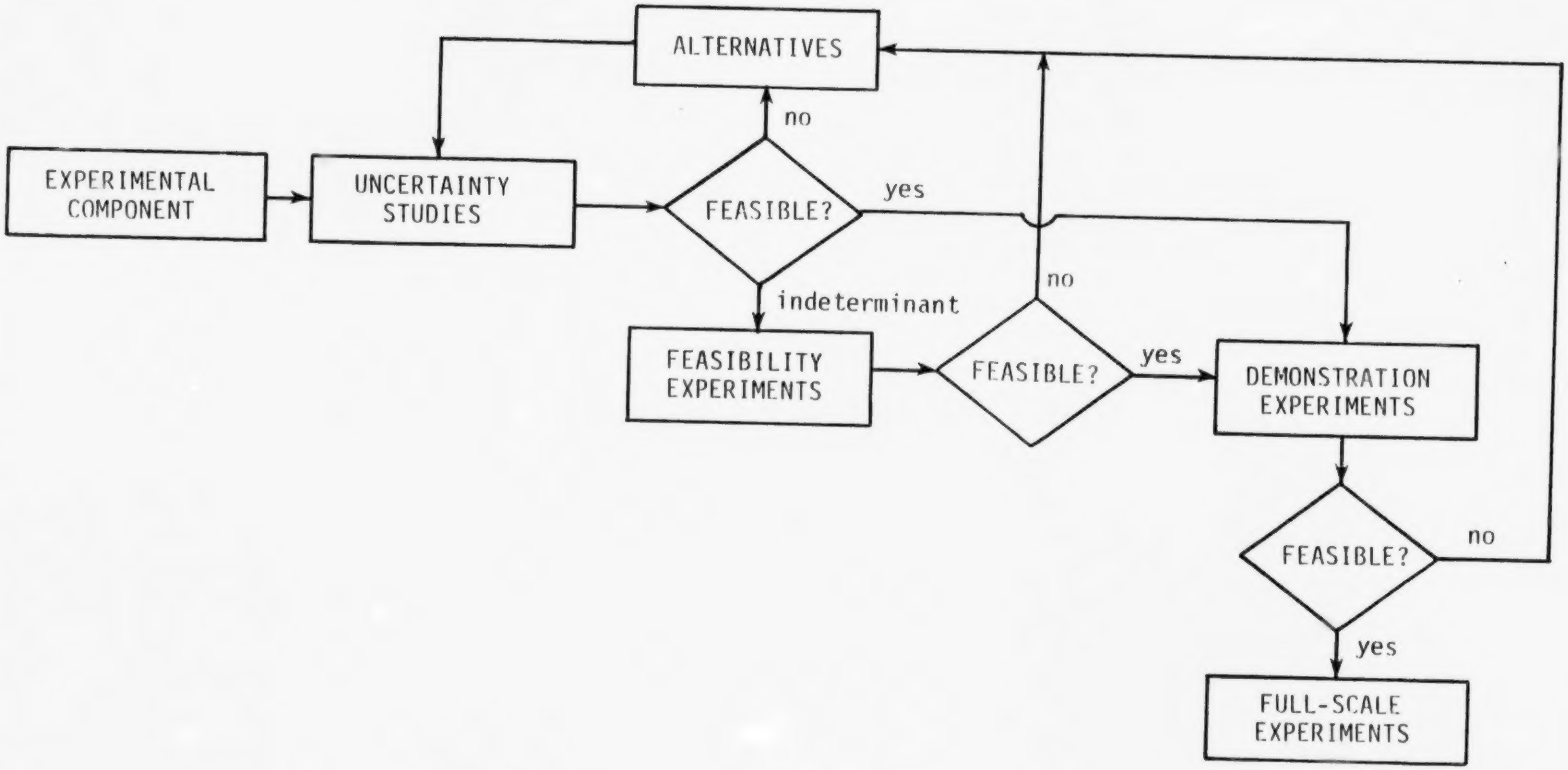

EXPERIMENTAL COMPONENT
UNCERTAINTY STUDIES
ALTERNATIVES
no
FEASIBLE?
yes
indeterminant
FEASIBILITY EXPERIMENTS
no
FEASIBLE?
yes
DEMONSTRATION EXPERIMENTS
FEASIBLE?
no
yes
FULL-SCALE EXPERIMENTS

Figure 8-1. Decision network for staged approach.

and regional air quality model simulations are summarized in the following subsection. Feasibility experiments refer to pilot experiments which are conducted primarily to determine if experimental techniques operate as described in the plan. The experiments described in Section 8.4 are examples of this type of pilot experiment. Demonstration experiments refer to testing of techniques which if successful on a small scale are assumed successful at full scale.

Figure 8-2 presents a diagram showing potential pilot studies in relation to the three experimental components. Pilot studies could easily be conducted as components of more comprehensive model evaluation experiments.

8.3 Summary of Uncertainty Analyses

As part of the staged experimental concept, limited studies were performed to review uncertainty issues associated with various design components. The uncertainty analyses, which are described more fully in an accompanying report*, examine the feasibility of experiments and associated uncertainties using data analyses with existing data bases and model simulations. Some results of the uncertainty analysis are as follows:

Monitoring Site Spacing and Experimental Uncertainty

A statistical analysis was perfomed using the SURE data base of SO_2 and sulfate concentrations collected at 54 sites in the Northeast. Data include ambient concentrations of SO_2 collected and averaged over 1 and 24-hour periods and 24-hour average sulfate concentrations. Results are as follows:

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*Comprehensive Field Study Plan to Relate Pollutant Sources to Acidic Deposition: A preliminary study of uncertainties.

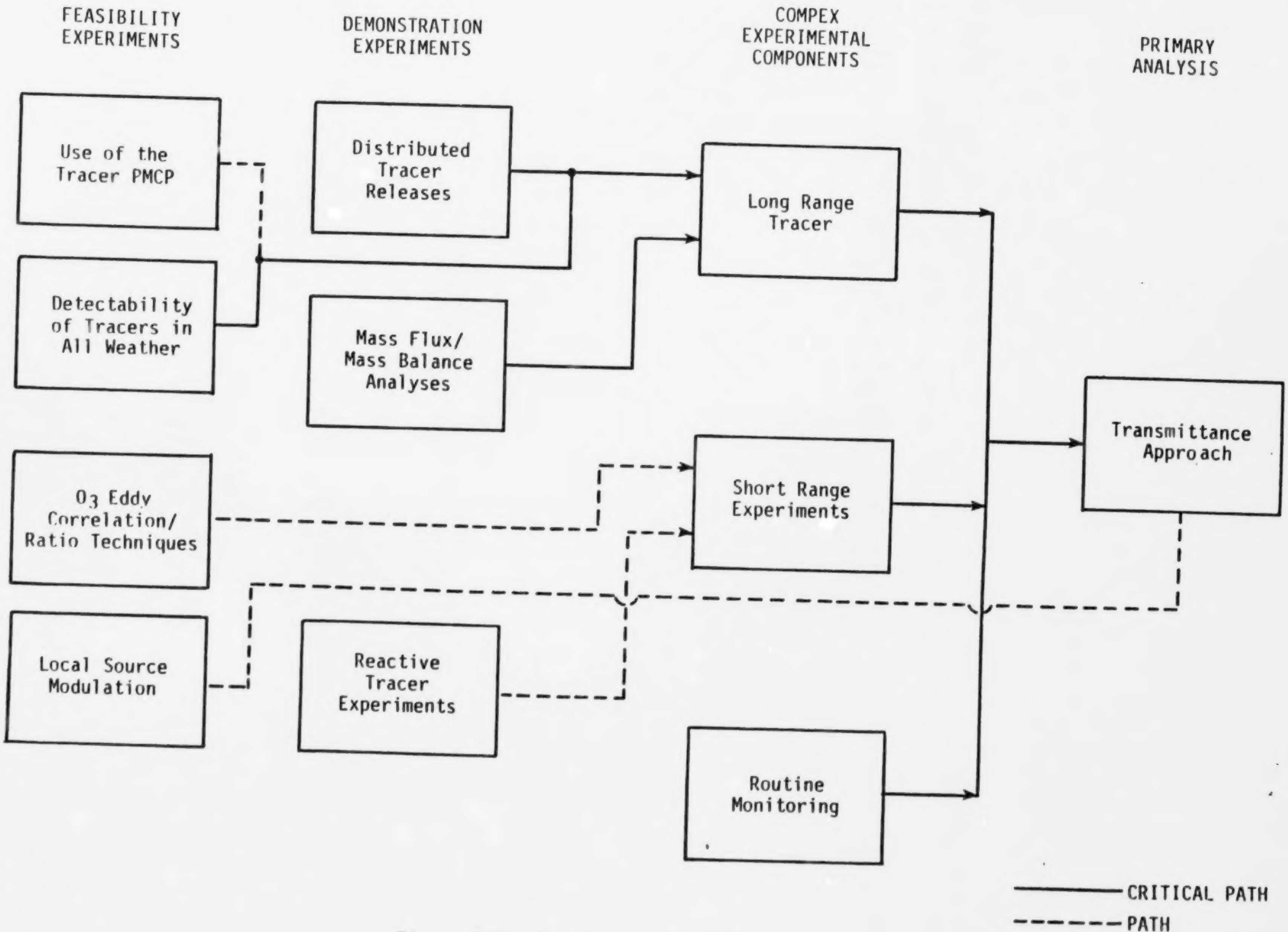
FEASIBILITY EXPERIMENTS
DEMONSTRATION EXPERIMENTS
COMPEX EXPERIMENTAL COMPONENTS
PRIMARY ANALYSIS
Use of the Tracer PMCP
Detectability of Tracers in All Weather
O_3 Eddy Correlation/ Ratio Techniques
Local Source Modulation
Distributed Tracer Releases
Mass Flux/ Mass Balance Analyses
Reactive Tracer Experiments
Long Range Tracer
Short Range Experiments
Routine Monitoring
Transmittance Approach
CRITICAL PATH
PATH

Figure 8-2. Major pilot studies.

- Sulfate is a more regional pollutant than SO_2. A model for interstation correlation can be given by:

$$r = \exp(-d/660\ \mathrm{km})$$

where d (km) is the distance between stations.

Use of the relationship suggests that the proposed average site spacing of 100-120 km would result in high positive correlations among sites (~ 0.85). This would aid in the analysis of sulfate data and compensate for missing data points. The mean squared error (MSE) and variation in average concentrations are also a function of separation distance for stations. Models for MSE agree closely with a distance related model.

$$MSE(d) = 0.45d^{0.45}$$

Twenty-four hour average SO_2 concentrations show a much more local pattern and spatial coherence in the concentration fields could not be found. Attempts at relating interstation correlations to distances provided poor fitting models implying an e-folding distance of much less than 140 km. The MSE among stations was approximately constant at 56 ppb (± 5.3 ppb). Results indicate that the proposed spacings will not adequately describe all features of the SO_2 concentration fields.

Hourly averaged SO_2 concentrations in some cases showed higher interstation correlations than those of 24-hour averages. Although this is not completely understood, it is thought that the data reveal periodicities of less than 24-hours due to local influences or instrument behavior. Hourly data were also used to examine the effects of point measurements in representing areal averages. Results obtained from grouping of SURE stations indicate that uncertainties in forming spatial averages are on order of 0.6 times the average concentrations. The results, although for only one pollutant, show the need for adequate grid spacing on data collection.

Examination of SO_2 and sulfate relationship indicate that the temporal patterns of concentrations differ markedly as do the spatial patterns. Sulfate concentrations have higher spatial correlation than SO_2. Spatial density functions for SO_2 have greater slope than those for sulfate which is consistent with the spatial patterns.

Modeling for Feasibility Analysis

Several design questions are amenable to study using regional air pollutant transport models. These include the detectability of tracers and required tracer release rates, the feasibility of mass balance/flux estimates and the feasibility of local source modulation experiments.

Some important questions in developing source/receptor relationships are what source areas are represented by the relationships, how the sources are simulated in experiments and what are appropriate tracer release rates for use in simulating pollutant results from a puff type long range transport model. Hourly results were reviewed for a one month period. The model simulations compared results generated for clusters of emissions sources with results from point sources in the same areas and their impact on a receptor area for distances in excess of 1000 km. The first result was very dramatic and indicated the differences in concentration predictions for single sources versus clusters of sources. This has a direct bearing on the proposed design in its confirmation of the use of distributed tracer releases to represent major emission source areas. The tests could not show whether representing all sources in an area by a few sources distributed in proportion to emissions rate and height would faithfully represent the real source area. This determination would require a demonstration experiment.

The second modeling result is a refinement on the release rates required to provide a detectable tracer plume at distances of 1000 km. Statistics for various tracer release rates were derived to show the frequency of detectability over background. The results are a refinement over the calculations in Section 4.1. They replace straight line trajectories with variable trajectories and show the effects of changing stability and mixing depth along a trajectories. The most important result is that a given source area influences a receptor area for a relatively short time.

In the example calculations, simulations showed that a particular group of sources in the Ohio River Valley could only expect to influence an Adirondack receptor approximately 40 percent of the hours in a month. This figure would vary for different sources and months but the conclusion of relatively infrequent influence can be generalized. This reinforces the design suggestion of maintaining an active (forecasted) tracer release program with potential release sources in a large arc around the target receptor area.

Model results also showed that the detectability is not very sensitive to small changes in tracer release rate. For example, if a source is detectable at five times background 35 percent of the time, an increase in detectability to 50 times background would require a release increase of at least a factor of 10. Such an increase in emissions would only increase the frequency of detectability at 5 times background a few percent.

The detectability of tracers was also investigated in regard to source modulation experiments. Tests described in Section 5.3 would attempt to describe the changes in concentration and deposition patterns which might exist over the long term in response to a one-week cycle of emissions modulation at three New York State power plants. The model results indicated that it was doubtful that the plants identified could make an indentifiable modulation in the concentration patterns relative to background. This conclusion suggests that the local source modulation experiment as described is infeasible. A decision as to whether the experiment could be completed in the vicinity of a larger source or in an area with lower background concentrations would require further study.

Analyses of Mass Balance Approaches

Analyses were performed to investigate the use of mass balance techniques in determining depletion rates and in evaluating the detectability of sulfur-34 in dry deposition experiments. The experiments, as designed, utilize mass balances and sulfur ratios as techniques to determine dry deposition rates. Modeling simulations using sulfur mass balance equations over mesoscale distances indicate that little tolerance would be permitted in measurements for a flux difference approach. Uncertainties associated with a plume depletion technique such as Horst's will need to be determined through a demonstration experiment. Use of the differences in sulfur-34 to SF_6 ratios to estimate deposition at distances of 20 to 50 km was investigated more directly by modeling. Estimates of loss rates versus separation distances indicate that the precision needed in SF_6 measurments is less than one percent, making success of this portion of the experiment questionable.

Analyses of Air Mass Trajectories

The transmittance approach depends on an accurate determination of plume position or path to estimate pollutant losses between the source and receptor. The method used in the COMPEX analysis will be a determination of trajectories through the use of ground level tracer data collected in the long range tracer component. Trajectories will also be determined using analytical trajectory techniques and data derived from objective analyses of winds or outputs from forecast models. To qualitatively assess the potential success of deriving trajectories from the tracer data, the CAPTEX surface perfluorocarbon measurements were analyzed. The data show distinct tracer masses can be tracked on a sampler network covering the Northeast. In some cases, the tracer plumes appear unexpectedly narrow while in others, shearing of the plumes is evident.

The tracer sampling networks for CAPTEX was established with sites roughly in arcs around the release points. Spacing between arcs was approximately 100 km and crosswind spacing was equal to approximately twice the expected plume crosswind standard deviation. In analyzing the data, it appeared in some cases that the grid spacing was insufficient but in most cases the insufficiency was due to missing data.

The CAPTEX review resulted in the following changes in the COMPEX design:

- Refinement of the coarse sampling grid resolution
- Confirmation of the ability to determine trajectories from tracer concentration data, and
- Encouragement of an active maintenance and quality assurance program to assure the maximum collection for analysis.

Review of the ACURATE Transport Experiment

Heffter et al (1984) reported data on a long-range transport study during which Krypton-85 released from operations at the Savannah River Laboratory was sampled at four sites as far as 1050 km from the source. Ground level sampling over 12 hour intervals was conducted over approximately 14 months. The data are of interest because of the parallels between SRL release study and the proposed long-range transport component of COMPEX.

Analysis of the ACURATE data studied the potential influence of releases at the SRL site on receptors. Releases from the plant occurred approximately 2 days in each three. Concentration events were counted for periods when

Krypton-85 exceeded background concentrations. Analysis of the data indicates that inverse relationships of frequency and separation distance exists. The probability of a tracer from a source influencing a receptor drops off sharply between 325 and 1050 km. The frequency of trajectory detection in all cases ranged from approximately 10 to 30 percent with the lowest frequency at the largest distance. For concentrations 10 and 100 times background, the frequencies rapidly full off to as little as one percent of the time.

The data are helpful in pointing out that the potential to measure source contribution at a receptor point is small. The results emphasize the importance of the following elements of the program design:

1. Distributed releases
2. A large sampling grid
3. Use of forecasted trajectories and multiple potential sources on a large arc to improve the probability of observing tracers and tracer tagged pollutants on the fine mesh grid

8.4 Feasibility Studies

Three possible types of feasibility experiments are described. Approximate costs for these experiments are summarized in Section 10.

8.4.1 Tracer Related Feasibility Experiments

Problem: The most important issue on the use of long range tracers in the COMPEX design is the question of detectability of the tracers in all weather conditions. The strong potential exists for mesoscale disturbances to significantly change the distribution of tracers in the transport layer to either very disperse patterns or patterns with very sharp and unexplained discontinuities. Such disturbances also pose problems for regional models and as a result, the pilot studies also contribute to the data base for model evaluation.

Approach: Plume tracking experiments using an inert tracer could be performed using ground level and aircraft sampling over mesoscale distances (200-300 km). The distance scale is less than that of the long range tracer components of the design but results would be extrapolated to full scale. The distance scale selected provides an adequate distance for detecting tracer plume. It is large enough to simulate interactions of the tracers in and above the mixed layer during meteorological conditions under which dramatic transfer mass could occur (e.g., nocturnal jets and other large shear zones, cloud venting and frontal discontinuities and lifting).

The experiment would answer questions of whether the plumes could be tracked at various release rates under a variety of meteorological conditions. In addition, the study would examine the potential for venting to the free troposhere and the relationship of transported plumes and ground level measurements. A possible approach would be to construct a series of short experimental tracer releases in varying meteorological conditions and track the plume elements by aircraft and ground level samplers.

The experiments provide inputs to the model evaluation data base. The research and engineering models developed by NCAR will be Eulerian and with a spatial resolution of approximately 80 km. At this scale the pilot tracer studies will provide some information applicable to evaluation of the models. Data from the experiments will allow an evaluation of predicted concentration profiles and transport direction as well as the effects of disturbances on predicted concentrations fields.

Problem: PMCP has been identified as a potential tracer for long range tracer experiments. It is important to test the tracer in an atmospheric setting to determine if it has the same characteristics as previously used perfluorocarbon tracers.

Approach: This experiment might be considered a demonstration experiment but was included here because testing of the tracer could be performed concurrently with the detectability experiments discussed in the previous subsection. During the experiments, coincindent releases of PMCP could be made concurrently in a fixed ratio. Monitoring of tracer ratios at the release point and the downwind receptors would provide information on both the detectability of tracers under all weather conditions, the conservatism of the tracers and the operational feasibility of using the tracer.

8.4.2 Feasibility Studies for the use of the O_3 Eddy Correlation/Ratio Technique for Dry Deposition

Problem: O_3 flux estimates have been made using ozone eddy flux techniques in aircraft. One method of determining dry deposition rates in the short range experiment component is to use sulfur and nitrogen oxide and ozone eddy flux estimates in ratios to estimate the sulfur and nitrogen fluxes from aircraft ozone data. It represents an approach which requires testing.

Approach: A short term experiment should be designed consisting of measurements of eddy fluxes of ozone and other pollutants at two or more distinctly different sites. In addition, eddy flux measurements will be made by an airplane over a very small uniform area. Ratios derived from the surface measurements will be applied to the ozone flux data. A qualitative assessment of performance for the technique will be made by comparing the results of the ground level measurements with the aircraft derived data. If the method is successful, spatially representative deposition rates obtained can be used to evaluate the deposition parameters used in regional modeling.

8.4.3 Signal Detection for a Source Modulation Experiment

Problem: A short range source modulation experiment has been proposed as an experimental element. Source modulation experiments appear to be infeasible because of limited detectability of the modulation in concentration and deposition data and the high costs of modulations. Reducing the magnitude of the emissions modulation to reduce costs reduces the detectability. Preliminary model simulations indicate that a source modulation experiment may not be useful in the Adirondacks region because of detectability problems. A source modulation experiment may be feasible in a more isolated location but in either case, this determination would require additional simulation and analyses.

Approach: Feasibility studies for source modulation require an assessment of uncertainties associated with measured concentration and deposition data as the values against which the modulation patterns must be compared. A source modulation experiment will involve:

- Selection of a receptor area with low background variability by an analysis of currently available network data.
- Identification of sources which influence the receptor and have emissions which can be modulated.
- Determination of the potential patterns of modulation for the sources under study.
- Testing with regional models to estimate the effects of the modulations.
- Long-term ground level sampling of modulated emissions and tracers from the source area and concentration data collected in a receptor area hundreds of kilometers from the source.

8.5 Demonstration Experiments

Subjects for demonstration experiments are described below.

8.5.1 Demonstration Studies of Distributed Tracer Releases

Problem: The COMPEX design is intended to provide an experiment program which would be useful in showing the effects of large emissions areas on deposition at sensitive receptors. The scale of the emissions areas considered is 100 km and the design uses multiple point releases in such an area to represent actual SO_x emissions. Preliminary modeling has indicated a need to use distributed releases rather than point sources in tracer studies. Simulations indicate large differences in results from individual point sources versus sources represented by distributed releases. A need remains to determine quantitatively whether and at what distance downwind the distributed tracer releases provide a fair representation of the real emission patterns.

Approach: The effects of distributed source releases should be determined by tracer and ambient concentration measurements over mesoscale distances. The experimental components include:

- Tracer releases from emission sources as a distributed release.
- Determination of actual emissions in a limited emissions area.
- Sampling of tracer concentrations and sulfur oxides in cross-sections at various distances away from the source region.

8.5.2 Demonstrations of Tracer Use in the Transmittance Approach

Problem: The most complicated issue in the experimental design is the measurement program and use of tracers in the transmittance approach. Use of tracers in long range experiments has been demonstrated in the CAPTEX experiments and questions about their detectability are described above. Remaining questions arise primarily in the use and calculation of fluxes in large vertical slabs of the atmosphere.

Approach: A demonstration experiment for mass flux estimates consists of flux measurements over a grid of the same scale as that planned for the long range transport component. A possible scenario is to establish a line of ground level sulfur oxide analyzers and wind concentration profilers perpendicular to the prevailing wind in a region expected to receive high pollutant concentrations. The line will extend for a distance of at least 100 km with samplers located at 20 km intervals. During experimental periods, aircraft will fly measurement patterns to sample vertical profiles of SO_x and cross wind integrated concentrations. Analysis of the data sets from three types of measurements will indicate the potential for this technique in the full scale experiments.

Important by-products of this test is an assessment of the use of the DIAL profiles to identify flight levels for aircraft studies and to provide data for model evaluation. Data for modeling will include information on spatial variability of concentration data particularly on the vertical profiles.

8.5.3 Demonstrations of the Use of Reactive Tracers for Deposition Studies

Problem: A short-term experiment has been proposed which combines the use of a reactive tracer with two methods to estimate dry deposition at distances from a few kilometers to 20-50 km. The methods are extensions of a three tracer method developed by Horst and a reactive to inert tracer ratio technique. This combination of techniques and the use of a reactive tracer requires further analysis as to whether the techniques are feasible and on the detectability and handling of the reactive tracer, sulfur-34.

Approach:

- The first element of the study involves laboratory scale experiments involving the exposure of carbonate impregnated cellulose filters to various concentrations of enriched $^{34}SO_2$ and performing analyses to determine the detectability of the gas.
- The second component involves testing of the three tracer surface depletion method and the ratio method for distances out to approximately 10 km from the release. Details of the experiment would be the same as those of the plan (Section 5.1) except in the distance over which the technique was applied. Ten kilometers places a severe test on the surface technique due to assumptions of homogeneity and at the same time provides sufficient distance for a good test of the ratio technique.

SECTION 9

QUALITY ASSURANCE PROGRAM

The quality assurance (QA) program applied to the comprehensive field study will serve several functions. First, it is designed to ensure the accuracy and completeness of the project's data base. Second, it will establish the traceability and repeatability of measurements, and provide error estimates for each type of data collected. Finally, the QA program will provide a mechanism to expedite rapid and controlled identification and correction of project problems, and to ensure that all affected members of the project team are apprised of any problem, its solution, and its impact in the final archived data.

All portions of the project affecting the final values in the data archive will be subject to the quality assurance program. This includes all project sponsored field measurements, data handling activities, and data archive management functions. Specifically excluded from the scope of the projects QA program are measurements provided by external sources, such as the National Weather Service and currently operating precipitation chemistry networks, which are already subject to their own quality assurance programs. COMPEX will rely on the external QA programs to ensure the quality of the external data and to provide estimates of the accuracy of this data. The external accuracy estimates will be included with the COMPEX data base. The project QA program will encompass data collection through delivery of valid data to the analysts and researchers. The QA program will not review the analytical approaches utilized by researchers or certify their results and conclusions.

The quality assurance program will be an independent and cooperative part of the overall project design. QA audits will be scheduled in conjunction with the project manager and the project team being audited. The QA team will report directly to the project manager, and will also ensure that each affected data handling group is apprised of significant QA findings.

Schedules for resolving project problems and significant QA findings will be established by the overall project manager, the QA team, and the responsible data handling group. The QA team will track the problem resolution schedule and notify the project manager if significant delays are encountered.

The quality assurance program design will be based upon the requirements of the EPA Quality Assurance Handbook for Air Pollution Measurement Systems, EPA, and SLAMS Regulations (40 CFR58, Appendices A and B), and the Nuclear Regulatory Commissions requirements (10 CFR50, Appendix B). Detailed procedures for each data collection and data handling system will be developed cooperatively by the QA team and the data handling groups. The cooperative approach to procedure development is being taken because many of the measurement systems that will be used are highly specialized and each research group is qualified to develop procedures specific to their own systems. Overall procedures to be followed by all project groups (such as document control procedures) will be developed by the QA team. The compliance of each data handling group to the procedures will be audited by the QA team. Specifically, it is expected that procedures and manuals will be developed covering the following project areas:

- Quality Assurance Program, Objectives, and Organization (project-wide)
- Document Control (project-wide)
- Procurement, Testing and Acceptance Procedures (system-specific)
- Specifications, Procedures, and Drawings (system-specific)
- Pre-test Preparation (system-specific)
- Maintenance Procedures (system-specific)
- Calibration Procedures (system-specific)
- Sample Collection (system-specific)
- Sample Analysis (system-specific)
- Data Reporting (project-wide)
- Corrective Action (project-wide)
- Training (system-specific)
- Interlaboratory and Intralaboratory Testing (project-wide)
- Audit Procedures (project-wide)
- Data Validation (system-specific)
- Quality Reporting (project-wide)

The QA team will develop all the "project-wide" procedures and will cooperate with each measurement group to develop the "system-specific" procedures. Both the project-wide procedures and the system-specific procedures, subsequently divided into the field measurements program, the laboratory analysis program, and the data archiving program, are discussed in the remainder of this section.

9.1 Project-Wide Quality Assurance

The project-wide quality assurance procedures and manuals will be designed to ensure efficient communication and adequate documentation for all project participants. A large variety of research groups will actively participate in the project, and it is essential that their activities and results are clearly documented, and that any problems are resolved rapidly and in a controlled manner. The quality assurance plan will specify the overall QA objectives and organization. The document control procedures will set forth the types of documents to be controlled, and the procedures for distribution of controlled documents. Data reporting procedures will provide specifics regarding format types, reporting schedules, error correction mechanisms, and an overview of data validation/invalidation procedures. The corrective action procedures will provide a mechanism to ensure that rapid, controlled and documented steps are taken to solve data related project problems. This procedure also ensures that any affected data can be identified, corrected, or deleted. The interlaboratory and intralaboratory testing procedures will establish testing accuracy targets and requirements for repeat sampling, blanks, and spiked samples. The testing procedures will also require tracability of project standards to nationally recognized standards. The frequency and format for both performance and systems audits will be established in the audit procedures, and the requirements for QA reporting will be established in the quality reporting procedures.

9.2 Field Measurements Quality Assurance

Reliable and accurate field measurements are essential to meet the overall project objectives. This requires that the measurements should be traceable to recognized standards and should be repeatable. Further, the data collection systems should not suffer from significant downtime. A diverse set of measurements will be collected using a wide-variety of equipment, techniques, and personnel. The QA team will cooperate with the field measurement teams to establish workable procedures to ensure proper operation of each system. The system-specific procedures, as listed in Section 9.1 will be tailored to the needs of each measurement group, and each group will be audited based upon both the project-wide and the individual system-specific procedures.

System audits will be conducted periodically to ensure that the projects' procedures are being followed. A systems audit will consist of a thorough on-site review of the facilities, equipment, training, procedures, record-keeping, data validation, and reporting aspects of each group's efforts. Systems audits will be used to asses the adequacy of established procedures and the level of compliance with the procedures. Systems audits on a quarterly basis will be adequate unless a persistent problem is found.

Performance audits are used to assess the quality of the data being generated and to identify problems in a timely manner. Measurement systems will be audited in-situ, and will be challenged with recognized, traceable standards throughout each system's operational range. The data generated during audits will be tracked through the data handling system to test the data transfer mechanisms. For most routine field monitoring equipment, this approach will suffice. However, independent performance audits of specialized measurement systems, and aircraft mounted monitors present unique problems. For many specialized measurement systems auditing techniques may not be readily available, and performance tests may be possible only for limited conditions, or perhaps not all. For example, aircraft mounted gas monitoring and particle sampling equipment is expected to be pressure and temperature sensitive. It is not possible, however, to test the response of the instruments throughout their nominal concentration range under a broad spectrum of actual flight conditions. Aircraft payload weight and cost limitations make it impractical to introduce a spectrum known concentration gases into the aircraft's sampling intake manifold during actual flights at a variety of altitudes. Generally aircraft mounted monitors are audited only on the ground and in pressure chambers as appropriate. Daily multi-point calibration of aircraft monitors, frequent in flight span checks and rapid data processing and review are the most useful tools to assure that valid data are being collected from mobile monitors and specialized measurement systems.

9.3 Laboratory Quality Assurance

One or more centralized laboratories will process a large number of field samples to obtain a variety of data types, including tracer concentrations and rainwater chemistry measurements. Field samples are expensive to acquire, and their analyses is often repetitive. It is crucial that the laboratories maintain high standards and vigilant quality control in order to produce a reliable data set. Clear procedures are essential, and an expert laboratory supervisor should be available at all times to address problems that the analysis technicians may encounter. Further, adequate training for the analysis technicians is needed to ensure that errors are identified and corrected.

Traceable and repeatable laboratory standards will be established at the outset of the project, and maintained throughout its duration. Laboratory protocols to establish interlaboratory agreement on the standards will be established. A schedule for instrument calibrations will be established to guard against response deterioration, and records of calibration results will be maintained for all equipment. Data handling in the laboratory will be automated as much as possible, to avoid transcription errors. Systems audits will be used to ensure that calibration schedules and data handling procedures are being followed. Performance audits will utilize known concentration samples to test the laboratory's response. In addition, blind audit samples will be submitted from the field, along with real samples, and the results of these analyses will be tracked throughout the sample handling, analysis and data archiving procedure. The blind samples will consist of blanks, spiked, and replicate samples, and will be indistinguishable from routine field samples to the analyst.

9.4 Data Archive Quality Assurance

The volume of data generated by the field measurements program will require computers to enable researchers to access and analyze it. Ensuring proper data handling is equally important as ensuring proper field measurements. The role of the quality assurance group in checking the data archiving activities is to systematically review all data handling and transfers from field data logging through delivery of final data to the research community.

The following elements will be subject to procedural control and QA auditing:

- Documentation governing the development and verification of software.
- Standards, practices, and conventions applied to software development.
- Configuration management procedures for controlling software and implementing software changes.

- Special tools and techniques that will be used to test software and support the data QA effort.
- Methods and facilities used to maintain and protect controlled versions of software, data, and documentation.

Systems audits of the data archiving program will review the procedures in place and ensure that data transfers, software modifications, and data base modifications are properly documented. Performance audits will include tracking data from the field to the archive, independent collection and reduction of field data, and comparisons of the QA data sets to the data archive's data sets. In addition, data sets with known statistical distributions will be submitted and tested in order to check their integrity after processing through the archiving software.

9.5 Scheduling and Audit Reporting

A schedule for systems and performance audits will be established at the outset of the project. Initially, the QA team will work extensively with the individual research groups establishing procedures. Early audits are expected to be frequent, in order to ensure that procedures are being followed, and to identify unworkable procedures that must be modified. Later, systems and performance audits will be scheduled quarterly, or more frequently if a problem area is identified. The audit team will work with each group to resolve problems during the audit.

Formal audit reports will be prepared following completion of each audit. These reports will be supplied to the program manager, the group being audited, and any other project groups significantly affected by the audit's findings. The project manager will be informed verbally of significant project problems while the audit team is still on-site. In this way, rapid corrective action can be initiated. At the end of the project, the QA team will submit an overall report containing estimates of the accuracy of each data type in the archive.

SECTION 10

ESTIMATED COSTS

A preliminary cost estimate has been developed based on the experimental program and analysis approaches presented in the previous sections.

10.1 Cost Summary and Basis

Table 10-1 presents the cost estimate broken down by major elements in parallel with the discussion in the text. The estimated cost of the COMPEX program is $110 million. Cost distribution was developed from total task estimates and is also given in Table 10-1. These estimates include the costs of inert and reactive tracers which by themselves contributed 22 percent to the total.

Some important points should be considered in examining the cost estimates:

- Tracer costs are a significant portion of the total project budget. The costs of the reactive tracer sulfur-34 has been estimated to be $12 million which may not completely cover costs of production, conversion to SO_2, and distribution prior to the experiments nor do they include costs of releases or sampling. The high cost of reactive tracer experiment may not be justifiable in view of expected results.
- In addition to the tracers, another sensitive, major cost item in the program is the potential cost for analyzing filter packs from the routine monitoring network. Reductions of costs may be possible by development of a more refined analysis technique or system, and/or selection of a subset of the filters for analysis.
- Costs in Table 10-1 were developed individually by task. The task costs are summarized in Table 10-2.
- The cost estimates do not consider interactions of COMPEX with other government programs nor do they consider equipment currently in use by the government. Much of the equipment identified, particularly high price items is necessary for the conduct of the programs such as PRECP and STORM. For example, common use of one wind profiler among programs would result in savings in the cost estimate of approximately $700,000. Smaller savings would be realized by careful planning of the routine monitoring program. Perhaps half of the required precipitation chemistry monitoring equipment required currently exists on existing monitoring grids.

TABLE 10-1

COST SUMMARY FOR THE TOTAL PROGRAM BY COMPONENT

	Estimated Cost	Fraction of Total (%)
1.0 Long Range Experiments		
1.1 Tracers	9,434,400	22
1.2 Tracer Sampling and assay	9,396,980	
1.3 Aircraft operation and assay	4,898,380	
2.0 Short Range Experiments		
2.1 Tracers	15,563,640	27
2.2 Tracer Sampling and Assay	4,172,460	
2.3 Deposition Experiments	10,040,650	
3.0 Routine Monitoring		
3.1 Pollutant Monitoring	27,482,125	28
3.2 Precipitation Chemistry	2,911,655	
4.0 Meteorological Data	13,754,020	13
5.0 Operations Control	1,036,750	1
6.0 Quality Assurance	1,681,940	2
7.0 Evaluation, Reporting, Data Base	9,249,000	8
TOTAL	$109,622,000	

TABLE 10-2

BASIS FOR COMPONENT COST ESTIMATES

1.0 Long Range Experiments	
1.1 Tracers for Long Range Experiments	
A. Tracer Material	
• Perflurocarbons, 10 kg/hr x 24 hr (day x 121 days x $100/kg x 2 tracers	5,808,000
B. Release Equipment (mechanisms, metering, recording)	
• Perflurocarbons, 5 sites x 3 areas x $20,000 per unit	300,000
C. Staff & Expenses	
• 5 sites x 3 areas x 2 people x $40/hr x 8 hr/day x 240 days	2,764,800
• 6 sites x 3 areas x 2 people x 1 car/person x $40/day x 240 days	345,600
• 36 people x $25/day expenses x 240 days	216,000
SUBTOTAL	$9,434,400
1.2 Tracer Sampling and Assay (Fixed Sites, Perflurocarbons)	
A. Samples, 157 locations	
• Sampler bases, $3,000 x 157	471,000
• Sampler lids, $2,000 x 157 x 4	1,256,000
• Spare bases, 10%, $3,000 x 18	54,000
• Spare lids, 10%, $2,000 x 18	36,000
• Second battery for continuous operation, $25 x 157	3,925
• Battery chargers, $50 x 157	7,850
• Replacement batterys, $25 x 2 batteries x 50% replacement x 157	3,925
• Sample tubes, 157 x 23 x $15	54,165
• Tube media, (rough estimate)	10,000
B. Sampler Preparation (labor)	
• Bases $280 x 175 hrs	49,000
• Lids, ($125 + $150) x 175 hrs x 4 people	192,500
C. Servicing of lids during testing, $150 x 175 x 4 x 16 times/site	1,680,000
D. Service Maintenance facility (for repair and maintenance of samples)	
• $55/hr x 40 hr/wk x 52 weeks	114,000
• Test equipment, spare parts	20,000
• Shipping	7,000
E. Shipping of samples	
• 157 sites x $10 x 6 times x 2 ways	50,240
F. Sample Assay	
• 157 sites x samples/day x 365 days x 1/23 samples/lid x $500/lid	4,983,000

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

G. Installation of samples	
• $40/hr x 8 hr/site x 157 sites	50,240
• Transportation, $40/car day x 157 can days	6,280
• Daily expenses, $100/day x 157 days	15,700
H. Collection of Field Samples	
• $40/lb x 3 hr/site x 157 sites x 16 times/year	301,440
• Transportation, 15 cars x $40/day x 3 days x 16 times/yr	30,720
SUBTOTAL	9,396,980
1.3 Aircraft Operation and Data Assay	
A. Equipment Aircraft (prepare an instrumental and navigational package)*	
• Pollutant sampling $50,000 x 4	200,000
• Tracer sampling $20,000 x 4	80,000
• Navigational instruments $50,000 x 4	200,000
B. Operation	
• 4 hrs/ft x 2 ft/day x 121 days/yr x 3 acft x 121 days x $400/hr	1,161,600
• Ferry time, 2 ft/day x 2 hr/ft x 3 acft x 121 days x $400/hr	580,800
• Standby changes, 30% of flight cost (rough estimate)	522,720
• Spare aircraft for use when one of the main 3 are out of service for A&E or instrument service, standby changes only @ 1/3 of item above	174,240
• Aircrew, $50/hr x 40 hr/wk x 52 weeks x 3 x 2 people	624,000
• Daily expenses (aircrews) $100/day x 365 x 3 x 2 people	219,000
C. Transportation	
• 2 cars x $40/day x 365 days	29,200
• Air fare to rotate air crews, $500 x 16 times/yr x 6 people	48,000
D. Instrument maintenance and service	50,000
E. Sample Assay	
• Tracer, 6 min/sample x 4 hrs/flts x 2 flts/day x 121 days x 3 acft x 1/23 lids/sample x $500/lid	631,300
• Pollutant, 30 min/sample x 4 hr/ft x 2 ft/day x 121 day x x $65/sample	377,520
SUBTOTAL	$4,898,380

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* One spare instrument - navigational package is included to assume full operation an 121 days/year. It is assumed that $400/hr for aircraft flight hours include fuel and pilot

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

2.0 Short Range Experiments

2.1 Tracers for Short Range Experiments

A. Tracer Materials	
• ^{34}S 300 kg available	12,500,000
• SF_6 165 kg/hr x 110 hrs x $10/kg	181,500
• Freon 1,650 kg/hr x 110 hrs x $15/kg	2,722,500
B. Release Equipment	
• ^{34}S, metering, plumbing, recording	3,000
• SF_6, heat control, metering, plumbing, recording	5,000
• Freon, heat control, metering, plumbing, recording	5,000
C. Release Staff and Support	
• $40/hr x 3 x 40 hrs/wk x 26 weeks	124,800
• Transportation, 3 vehicles x $40/day x 7 day/wk x 26 weeks	21,840
SUBTOTAL	15,563,640

2.2 Tracer Sampling and Array for Short Range Experiments

A. Equipment	
• Samplers ^{34}S, 50 sites x $1,600	80,000
• Spares, 5 x $1,600	8,000
• Set up, 50 sites x 8 hrs/site x $40/hr	16,000
• Site preparation, power, roadways, pads, $4,000 x 50	200,000
• Operating expenses, $50/mo x 6 mo x 50	15,000
• Transportation to set up, 5 cars x $40/day x 14 days	2,800
• Daily expenses during set up, 10 people x $100/day x 14 days	14,000
• Samplers SF_6 and freon, DSI, 50 sites x $2,500	125,000
• Spares, 5 x $2,500	12,500
• Batteries, $25 x 50	1,250
• Battery chargers, $50 x 50	2,500
• Expendables, syringes, replacement batteries, etc .50 ea x 24/samples x 50 sites x 182 days + $25 x 50	110,450
• Towers, 5 sites x $30,000	150,000
B. Servicing Samplers (local people)	
• $40/hr x 10 people x 40 hrs/wk x 26 weeks	416,000
• Transportation, 10 vehicles x $40/day x 182 days	72,800
• Daily expenses, 10 people x 100/day x 182 days	182,000
C. Assay	
• ^{34}S (remote lab), 50 sites x 2/day x 91 days data x $270	2,457,000
• SF_6 and freon (on-site lab), 7 computer controlled GCs, 7 x $10,000	70,000
• Labor, $50/hr x 40 hrs/wk x 26 wks x 3 operations	156,000
• Transportation, lab people, 2 cans x $40/day x 182 days	14,560
• Air fare to rotate crews, $500 x 3 people x 8 times/6 mo	12,000
• Daily expenses, 3 people x $100/day x 182 days	54,600
SUBTOTAL	4,172,460

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

2.3 Deposition Experiments

Aircraft Operation		
A. Outfit one aircraft		
• Pollution sampling	$50,000	
• Tracer sampling	20,000	
• Navigational equipment	50,000	120,000
B. Operations		
• 16 hrs/area x 10 areas, average 6 hrs/day x 121 days x $400/hr		290,400
• Ferry time, 2 hrs/day x 121 days x $400/hr		96,800
• Standby charges (at 1/3 of flight cost, rough estimate)		129,070
• Air crew, $50/hr x 40 hr x 40 hr/wk x 52 wks		104,000
• Transportation, 1 car x $40/day x 365		14,600
• Daily expenses, 1 person x $100/day x 365		36,500
• Airfare to rotate crew, $500 x 16 times/yr		8,000
C. Sample Assay		
• Tracer, 10 samples/hr x 6 hrs/day x 121 days x $500/23		157,800
• Pollutant, 10 samples/hr x 6 hrs/day x 121 days x $65		471,900
SUBTOTAL		1,321,070
DIAL Lidars		
A. Equipment, 5 units x 500,000		2,500,000
B. Operations		
• $85/hr x 40 hrs/wk x 52 wks x 5		884,000
• 2 x $55/hr x 40 hrs/wk x 52 wks x 5		1,144,000
• Transportation, 1 cars x $40/day x 52 wks x 5		73,000
• Daily expenses, $100/day x 3 people x 365 days x 5		547,500
• Air fare to rotate crews, $500 x 3 people x 5 sites x 16 times/yr		120,000
C. Data Assay		
• $2,000/data day x 121 days x 5		1,210,000
D. Supplies and Expendables		
• $10,000/mo x 12 x 5		600,000
SUBTOTAL		7,078,500
Surface Measurements		
A. Staff		
• $45/hr x 40 hrs/wk x 52 wks x 6 people		561,600
• $15/hr x 40 hr/wk x 52 wks x 4 people (local temp)		124,800

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

B. Equipment		
• Towers - 4 units x $50,000 (50 m)		200,000
• Tower instruments - 4 sets x $35,000 (with recorders)		140,000
• Misc.		100,000
C. Filters		
• 2 sites x 4 filters/day x 7 days/wks x 52 wks x $65		189,280
D. Transportation		
• 4 cars x $40/day x 365 days		58,400
• Air fare to state crews, $500 x 6 people x 16 times/yr		48,000
E. Daily Expenses		
• 6 people x $100/day x 365		219,000
SUBTOTAL		1,641,080
TOTAL DEPOSITION EXPENSES		10,040,650

3.0 Routine Monitoring

3.1 Pollutant Sampling

A. Hivols Samples for filter packs		
• 157 sites x $1,000		157,000
• Site prep, $2000/site x 157		314,000
• Power, $2000/site x 157		314,000
• Spare hivols, 16 x $1000		16,000
• Spare parts, maintenance, supplies $500 x 157		78,500
• Labor installation, ($40/hr + $30/hr) x 157 x 24 hr/site		263,760
• Transportation, set up crews, 15 cars x $40/day x 14 days		8,400
• Daily expenses, $100/day x 30 x 14 days		42,000
• Filters related materials $10/filter pack x 157 x 4/days 365 days		2,292,200
B. O_3 Samples		
• O_3 analyser	$ 5,700	
• Data logger and cassette	4,000	
• Calibrator	4,000	
• Manifold	800	
• Voltage regulator	950	
• Spare parts and exp.	1,500	
• Temp controlled shelter	3,000	
	$27,835 x 157	3,133,725
• Installation, ($40/hr + $30/hr) x 157 x 24 hr/site		263,760
• Transportation, 15 cars x 40/day x 14 days		8,400
• Daily expenses 100/day x 30 x 14		42,000
C. Operation		
• $40/hr x 157 sites x 2 hrs/site x 365 days		4,584,400
• Transportation, $.25/mi x 25 x 157 x 365		358,156
• Utilities $50/month x 12 months x 157 sites		94,200

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

D. Filter Assay	
• 157 sites and filters/day x 365 days x $65/filter	14,899,300
SUBTOTAL	27,482,125
3.2 Precipitation Chemistry	
A. 157 sites @ $2,655 per collector and rain gauge	416,835
• Spares @ 10% = 16 x $2,655	42,480
B. Installation	
• 157 sites x 8 hrs/site x $40/hr	50,240
C. Operation/Servicing to collect samples from the field	
• 157 sites x 90 precip. days/yr x 3 hrs/sample x $40/hr	1,695,600
• Transportation costs included	
D. Laboratory Assay	
• 157 sites and 90 samples/yr x $50/sample	706,500
SUBTOTAL	2,911,655
4.0 Meteorological Data	
A. Doppler Acoustic Wind System	
• 6 sites x $80,000	480,000
• Operation and Maint., 6 sites x $40/hr x 16 hrs/mos x 12 months	46,080
• Transportation, $40/day x 3 days/mo x 12 months	1,440
• Data reduction, 6 sites x 365 days x 3 hrs/data day x 40/hr	262,800
SUBTOTAL	790,320
B. Rawinsondes	
• NWS supplement, 2/day to 4/day, 16 sites x 365 x $250	1,460,000
• 1 site, 2 extra mass balance, 4/day to 8/day x 121 days	300,000
• 6 new sites at 4/day, $30,000 x 12 mo x 6	2,160,000
• Transportation, 2 cars x $40/day x 6 sites x 365 days	175,200
• Air fare, $500 x 12 people x 16 times 1 year	96,000
• Daily expenses, $100/day x 12 people x 365	438,000
SUBTOTAL	$4,629,200
C. Doppler Lidar for Wind Fields	
• 5 sites x $750,000	3,750,000
• $85/hrs + 2 x $50/hr x 40 hr/wk x 52 wks x 5	1,924,000
• Operation, $5,000/mo x 12 mo x 5	300,000
• Supplies and exp, $2,000/mo x 12 mo x 5	120,000
• Data Assay, $25,000/data month x 5	1,500,000

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

• Transportation, $40/day x 365 days x 5		73,000
• Air fare to rotate crews, 15 people x $500 x 16 times		120,000
• Daily expenses, $100/day x 15 people x 365		547,500
SUBTOTAL		8,334,500
TOTAL NET DATA		13,754,020
5.0 Operations Center		
A. Staff		
• Experimental Manager	$80/hr x 40 hrs/wk x 52 weeks	166,400
• Assistant and backup Supv.	$65/hr x 40 hrs/wk x 52 weeks	135,200
• Meteorologist	$65/hr x 40 hrs/wk x 52 weeks	135,200
• Data Review Staff		
Supervisor	$55/hr x 40 hrs/wk x 52 weeks	114,400
3 staff	$40/hr x 40 hrs/wk x 52 wks x 3	249,600
Secreterial support	$25/hr x 40 hrs/wk x 52 wks	52,000
B. Forecast Service (customer service from commercial forecast company)		
• Basic services @ $2,000/month x 12 months		24,000
• Special documentation $250/data day x 121 days		30,250
• Data transmission facilities terminal, fax, TTY; $1200/mo x 12		14,400
C. Rent for office space, 2,500 ft^2 @ $15/$ft^2$/yr		37,500
• Supplies @ $200/mo x 12 months		2,400
D. Equipment for Data Center		
• Tape readers	$35,000	55,000
• Chart readers		
• Recorders		
• Printers		
• Plotters		
• Mini computer	18,000	
• Data processing packages	2,000	
E. Transportation Expenses Related to Project		
• Air fare and local travel per diameter		10,000
• Per diam		2,000
F. Office Expenses		
• Telephone 400/month x 12 months		4,800
• Copy service 300/month x 12 months		3,600
SUBTOTAL		1,036,750
6.0 Quality Assurance		
A. Field Staff		
• $85/hr x 40 hrs/wk x 52 weeks		176,800

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

• $60/hr x 40 hrs/wk x 26 weeks	62,400
• 2 x $50/hr x 40 hr/wk x 26 weeks	104,000
• 2 x $50/hr x 40 hr/wk x 52 weeks	208,000
B. Special Test Equipment	
• Standards	
• Recorders	
• Expendables	165,000
C. Travel	
• 3 cars x $40/day x 365 days	43,800
• 3 cars x $40/day x 182 days	21,840
• Air fare, $500 x 3 people x 15 times/yr and $500 x 3 people x 8 times/yr	164,100
D. Daily Expenses	
• $100/day x 182 days x 3 and 100/day x 365 x 3	164,100
E. Data Evaluation and Reporting	
• Data processing $200,000	
• Data evaluation 400,000	
• Report preparation 100,000	700,000
SUBTOTAL	1,681,946
7.0 Evaluation, Reporting, Data Base	
A. Data Handling	
• Data entry, $30/hr x 40 hr/wk x 78 wks x 5 people	468,000
• Editing, $50/hr x 40 hr/wk x 78 wks x 2 people	312,000
• Preprocessing revising & cross check, computer $1,000	100,000
x 100 hrs 50/hr x 40 hr/wk x 26 wks x 2 people	104,000
• Data processing, computer, $1000/hr x 500 hrs	500,000
• Statistical routines, $1000/hr x 500 hrs	500,000
• Graphics, $500/hr x 100 hrs	50,000
B. Data Analysis	
• 85/hr x 40 hrs/wk x 104 weeks x 2	707,200
• 65/hr x 40 hrs/wk x 104 weeks x 10	2,704,000
• 50/hr x 40 hrs/wk x 104 weeks x 10	2,080,000
• 40/hr x 40 hrs/wk x 104 weeks x 2	332,800
C. Report Preparation	
• 85/hr x 40 hrs/wk x 26 weeks	88,400
• 65/hr x 40 hrs/wk x 26 weeks x 5	338,000
• 50/hr x 40 hrs/wk x 26 weeks x 5	260,000
• 40/hr x 40 hrs/wk x 26 weeks x 2	83,200

TABLE 10-2
BASIS FOR COMPONENT COST ESTIMATES
(continued)

D. Data Base	
• $85/hr x 40 hrs/wk x 13 weeks	44,200
• $65/hr x 40 hrs/wk x 13 weeks x 4	135,200
• $40/hr x 40 hrs/wk x 26 weeks x 5	208,000
• $1000 hrs x 10 hrs/wk x 13 weeks (computer)	130,000
E. Secreterial Support	
• $25/hr x 40 hrs/week x 52 weeks x 2 people	104,000
SUBTOTAL	9,249,000

Projected costs of the pilot studies are difficult to determine. Estimated costs of the pilot experiments are given in Table 10-3. The costs for three feasibility and three demonstration tasks are listed. Costs of the COMPEX program listed in Table 10-1 and 10-2 could be affected by the results of these studies.

The COMPEX design is oriented toward providing empirical source/receptor relationships and a data base sufficient for evaluation of regional acid deposition models. In addition to these objectives, the program represents an improvement in the state of knowledge on long-range pollutant transport and acidic deposition. As such program options are possible which would reduce the costs of the program by imposing additional constraints but the constrained program would still provide valuable information particularly for model evaluation and understanding acidic deposition. Section 10.2 provides a summary of some of these options with cost reductions based on Tables 10-1 and 10-2.

10.2 Program and Cost Options

The COMPEX design combines numerous elements in an attempt to satisfy objectives including the development of source/receptor relationships and providing a data base for model evaluation. The design was created using new and generally expensive techniques to provide a link between sources and resultant deposition. In addition, the plan was written independently of objectives and plans of other research efforts, particularly process and monitoring studies. A cost benefit study of the COMPEX components was not conducted although in reviewing the plan, it becomes evident that cost savings could be achieved particularly with additional constraints on the program. Options considered include:

TABLE 10-3
COSTS OF FEASIBILITY AND DEMONSTRATION TASKS

1.0 Feasibility Tasks	
1.1 Tracer Related	
1.1.1 All Weather Detectability Including • cloud venting • relationship of concentration aloft to ground-level concentration	550,000
1.1.2 PMCP Tracer	250,000
1.2 Dry Deposition Measurments	
1.2.1 Eddy Correlation Techniques	300,000
1.3 Signal Detection for Source Modulation	600,000
2.0 Demonstration Tasks	
2.1 Distributed tracer releases effectiveness	562,000
2.2 Transmittances/mass balances approach	5,000,000
2.3 Reactive tracer deposition experiment	2,050,000
TOTAL	9,312,000

- Use of equipment from other government studies.
- Removing the reactive tracer experiments from the design.
- Eliminating experiments using mass balance and eddy correlation/ratio techniques.
- Converting the study into a program providing data primarily for model evaluation.

A limited cost review was performed to evaluate each option.

Hardware cost estimates for the program appear to be significant when the high cost of remote sensing devices are considered. A rough estimate of the relative savings which could be achieved by equipment sharing with other government programs is relatively low due to the high level of tracer and labor costs in the program. It is expected that the cost savings is less than 5 percent of total estimated cost.

Reactive tracer experiments are extremely expensive due primarily to the production cost of sulfur-34. Preliminary studies indicated that there is substantial uncertainty in the methods used in this component. Deleting this aspect of the program would require increased reliance of the program on other dry deposition components and results from other research studies. Estimated costs savings obtained by deleting the component are approximately $20 million or approximately 18 percent of the program costs. This estimate does not include reductions in the analysis, management, and quality assurance components.

Total reliance on other programs to provide dry deposition estimates represents another option. Elimination of the aircraft eddy correlation/ratio experiments provides another increment for cost reduction which would not require a major change in program objectives. These experiments contribute approximately $3 million to the total program costs or approximately 3 percent exclusive of the analysis, quality assurance, and management costs.

Elimination of all dry deposition measurements by removing the local mas flux/mass balance experiments of the long range tracer component would require a change in objectives because the empirical source/receptor relationships could not be obtained without the mass transmittance approach. The resultant program would primarily be a routine monitoring program in which empirical source/receptor relationships can only be obtained by statistical inference or analysis with regional acid deposition models. Cost reductions from such a change would be substantial and would stem from three areas:

- Operational savings of approximately $51 million (≈ 46 percent of total costs)
- Analysis, quality assurance and management savings of approximately $5 million (≈ 5 percent)
- Savings from the elimination of some pilot experiments of approximately $9 million.

The resultant program would provide information on pollutant distributions from ground level sampling (including concurrent air and precipitation chemistry measurements), tracer concentration data from transport and dispersion experiments, and meteorological data. Pilot studies required would include studies of all-weather detectability of tracers, evaluations of distributed tracer releases and feasibility studies for the PMCP tracer.

REFERENCES

The references listed here contain sources cited in the appendices as well as in the main text.

Anthes, R. A., 1983: Regional Models of the Atmosphere in the Middle Latitudes, Monthly Weather Review, 111: 1306-1335.

Bilonick, R.A., 1983: Risk Qualified Maps of Hydrogen, Ion Concentration for the New York State Area for 1966 to 1978. Atm. Envir., 17 (12): 2513-2524.

Bilonick, R.A. and D.G. Nichols, 1983: Temporal Variations in Acid Precipitation over New York State - What the 1965 to 1979 USGS Data Reveal. Atm. Envir., 17 (6): 1063-1072.

Binkowski, F., 1984: Personal Communication - U.S. EPA.

Brillinger, D.R., 1975: Time Series Data Analysis and Theory. Holt, Rinehart and Winston, Inc.

Chan W., 1984: Personal Communication, Ontario Ministry of the Environment.

Chan W., D. Orr, and R. Vet, 1982: Acidic Precipitation in Ontario Study, An Overview: The Event Wet/Dry Deposition Network. API 002/82, Ontario Ministry of the Environment.

Dana, T., 1984: Personal Communication. Pacific Northwest Laboratory.

Dietz, R., 1984: Personal Communication, Brookhaven National Laboratory.

Dietz, R.N. and G.I. Senum, 1984: Capabilities, Needs, and Applications of Gaseous Tracers. Atmospheric Tracers Workshop. Santa Fe, New Mexico.

Draxler, R.R., 1983: Lagrangian Meteorology and Measurements of Acidic Precipitation at Washington, D.C., Atm. Envir. 17 (12):2525-2531.

Fawler, M.M., and S. Barr, 1980: A Long Range Atmospheric Tracer Field Test, Atm. Environ., 17(9):1677-1686.

Ferber, G. and J. Heffter, 1983: CAPTEX '83 Cross Appalachian Tracer Experiments: Revised Plan. NOAA ARL, Rockville, MD.

Ferber, G. and J. Heffter, 1984: Personal Communication, NOAA ARL.

Finkelstein, P.L., 1984: The Spatial Analysis of Acid Precipitation Data. Journal of Climate and Applied Meteorology, 23 (1): 52-61.

Foley, G. and G. Hilst, 1983: An Experimental Determination of Sources of Acidic Deposition in the Eastern U.S. and Canada.

Forrest, J. and L. Newman, 1973: Sampling and Analysis of Atmospheric Sulfur Compounds for Isotope Ratio Studies. Atm. Envir., 7 (5): 561-574.

Hall, F., R.H. Huffaker, R. Hardesty, M. Jackson, T. Lawrence, M. Post, R. Richter and B. Weber, 1984: Wind Measurement Accuracy of the NOAA Pulsed Infrared Dappler Lidar. Applied Optics, 23: 2503-2506.

Heffter, J.L., J.F. Schubert, and G.A. Mead, 1984: Atlantic Coast Unique Regional Atmospheric Tracer Experiment (ACURATE). NOAA Technical Memorandum ERL ARL-130.

Heisler, S. 1983: The Electric Power Research Institute National Emissions Inventory. Acid Rain in the Rocky Mountain West. Colorado School of Mines, Golden, CO.

Heisler, S. 1984: Emission Inventory Requirements for Deposition and Regional Air Quality Model Development: A Summary. First Annual Acid Deposition Emission Inventory Sumposium, Raleigh, NC.

Hicks, B., 1984: Background Notes on the Use of Sulfur Isotopes in Long Range Tracer Experiments. ATDL 84/10 Atmospheric Turbulence and Diffusion Division, NOAA Oak Ridge, TN.

Hicks, B., M. Wesely, and J. Durham, 1982: Critique of Methods to Measure Dry Deposition. Energy and Environmental Chemistry. L.H. Keith ed. pp. 205-223.

Hicks, B.B., M.L. Wesely, J.L. Durham and M.A. Brown, 1982: Some Direct Measurements of Atmospheric Sulfur Fluxes over a Pine Plantation. Atmospheric Envir., 16, (12), 2899-2903.

Horst, T.W., 1977: A Surface Depletion Model for Deposition from a Gaussian Plume. Atm. Envir., 11: 41-46.

Horst, T., J. Doran, and P. Nickola, 1983: Dual Tracer Experiments of Plume Depletion. Precipitation Scavenging, Dry Deposition, and Resuspension, Volume 2, eds. Pruppacher, Semonin, Slinn, Elsevier, NY.

Interagency Task Force on Acid Precipitation, 1984. Operating Research Plan. Washington, D.C.

Jansen, J., 1984: Personal Communication

Lenchow, D.H., A.C. Delony, B.B. Stankon, and D.H. Stedman, 1980: Airborne Measurements of the Vertical Flux of Ozone in the Boundary Layer. Boundary Layer Meteor., 19:249-265.

Liu, M.K., 1984: On Empirical Determination of Source/Receptor Relationships for Acid Deposition Problems, Systems Applications, Inc., Reprint SYSAPP-84/071. San Fafael, CA.

Mathews, E., 1983: Global Vegetation and Land Use: New High Resolution Data Losses for Climatic Studies. J. Climate and Appl. Meteor., 22:474-487.

Michael, P. 1984: Notes on the use of sulfur-35 as a long-range Tracer. Brookhaven National Laboratory.

Michael, P., 1983: Non-linearity of Acid Precipitation Processes: Preliminary Program Plan. Brookhaven National Laboratory, BNL33164.

Mobley, J. 1984: Current NAPAP Emission Inventory Activities. First Annual Acid Deposition Emission Inventory Symposium, Raleigh, NC.

NCAR, 1984: The National STORM Program, STORM-Central Phase. National Center for Atmospheric Research, Boulder, CO.

NCAR, 1983a: Regional Acid Deposition: Models and Physical Processes. National Center for Atmospheric Research, NCAR/TN-214+STR.

NCAR, 1983b: Regional Acid Deposition: Design and Management Plan for a Comprehensive Modeling System. National Center for Atmospheric Research, NCAR/TN-215+PPR.

Newman, L., J. Forrest, and B. Manowitz, 1975a: The Application of an Isotope Ratio Technique to a Study of the Atmospheric Oxidation of Sulfur Dioxide in an Oil Fired Power Plant Plume. Atm. Envir., 9:959-968.

Newman, L., J. Forrest, and B. Manowitz, 1975b: The Application of an Isotope Ratio Technique to a Study of the Atmospheric Oxidation of Sulfur Dioxide in an Coal Fired Power Plant Plume. Atm. Envir., 9:969-977.

Pack, D.H., et al., 1978: Meteorology of Long Range Transport. Atm Envir., 12: 425-444.

Peache, M.A., 1978: Sulfur Dioxide Measurements and Mass Flux Calculations in Support of the AMBIENS Field Experiment. Environmental Measurements, Inc. Technical Report EMI Project 1410.

Perhac, R., G. Hilst, P. Mueller, G. Hidy, T. Lavery, and J. Watson, 1981: EPRI Sulfate Regional Experiment: Results and Implications. EPRI EA-2077-SY-LD.

Priestley, C.H.B., 1959: Turbulent Transfer in the Lower Atmosphere. The University of Chicago Press, Chicago, IL.

Rodhe, H., Eliassen, I. Isaksen, F. Smith, and D. Whelpdale, 1982: Tropospheric Chemistry and Air Pollution. WMO Report No. 583, Geneva, Switzerland.

Ruff, R.E. and K. Nitz, F. Ludwig, C. Bhumralkar, J. Shannon, C. Sheih, I. Lee, R. Kumar, and D. McNaughton, 1984: Regional Air Quality Model Assessment and Evaluation, EPRI Report No. EPRI EA-3671.

Schwartz, S.E., 1984: Personal Communication, Brookhaven National Laboratory.

Shannon, J.D. and Hicks, B.B., 1977: Box Budget and Tracer Experiments During AMBIENS. Radiological and Environmental Research Division Annual Report, Atmospheric Physics, Arogonne National Laboratory ANL-77-65, Part IV.

Smith, F., C.E. Decker, R.B. Strong, J.H. White, F.K. Grey, and W.D. Beck, 1983: Estimates of Uncertainty for the Plume Model Validation and Development Project Field Measurements Plains Site. Report EA-3082. Electric Power Research Institute, Palo Alto, California.

Van Egmond, N.D., and D. Onderdelinden, 1981: Objective Analysis of Air Pollution Monitoring Network Data, Spatial Interpolation and Network Density. Atm. Environ., 15(6):1035-1046.

Vet, R.J. and R. Gilber, 1984: The Canadian Air and Precipitation Monitoring Network (CAPMoN): A Description. Atmospheric Environment Service, Downsview Ontario, Canada.

Weisenfeld, J.R. and W.T. Kreiss, 1982: The Source-Receptor Relationship in Acid Precipitation: Implications for the Generation of Electric Power from Coal. United States DOE Report DE82 019307.

APPENDIX A

SUPPORT DATA AND ANALYSIS AVAILABLE FROM RELATED STUDIES

A.0 SUPPORT DATA AND ANALYSIS AVAILABLE FROM RELATED STUDIES

A.1 Emissions Data

The long range tracer component of the combined experiments will simulate pollutant transport and dispersion by tagging emission sources with a perfluorocarbon tracer. To relate tracer emissions to pollutant emissions and to provide a data base for model evaluation, information on emissions levels and characteristics is required. A starting place for emissions inventory development is with two ongoing emissions inventory studies:

EPA Comprehensive Emissions Inventories

EPA Office of Air Quality Planning and Standards (OAQPS) is funding the development of emissions inventories to support model development and evaluation studies related to acid deposition. The primary inventories produced by the study will be a 1980 base year inventory designed for use with Lagrangian models and an updated 1984 inventory for use with Eulerian models. The emission inventory for the 1980 base year will build upon the National Emission Data System (NEDS) which is maintained by EPA's OAQPS. This inventory, which contains both point and area sources, will be edited and validated using other data sources and will be augmented with Canadian data. Seasonal emissions distributions will be included, and primary sulfate emission factors will be developed and applied to yield an emission inventory for SO_2, NO_2, VOC, and sulfates. A methodology for uncertainty analysis will be provided and the inventory will be available to users either by direct computer access or magnetic tape.

The emission inventory for the Eulerian acid deposition atmospheric model will build upon the NEDS information and the emission inventory developed for the Eulerian oxidant atmospheric model. This inventory will be edited, validated, and presented with results of an uncertainty analysis. VOC emissions will be disaggregated by photochemical reactivity class, and emission factors will be developed and added for sulfates, NO_2, NO, HCl, HF, NH_3, and alkaline dust. Temporal and spatial allocation factors will be developed and implemented to yield hourly emissions for a typical weekday and weekend day and grid-level emissions estimates (such as 20 km x 20 km). The natural sources emission inventory and Canadian emission inventory will be merged with this inventory to form the NAPAP Emission Inventory.

Electric Power Research Institute

The Electric Power Research Institute is funding a study to produce a 1982 emissions inventory for most major pollutant groups (Heisler, 1983). The inventory will be similar to the previous Sulfate Regional Experiment (SURE) inventory in its design. The data base will include sources allocated to 80 km grid squares at multiple levels as well as in a major point source file. The inventory will be generated primarily from the National Emissions Data System (NEDS) with supplementary data from Canadian sources and direct inquiries to state agencies and individual emission sources. Pollutants considered are sulfur oxides (SO_2 and sulfate), oxides of nitrogen (NO, NO_2), and hydrocarbons (8-9 reactivity classes). The emission data will be tored as seasonal averages and as means for each three hour period in a day.

The resulting data set will be validated for at least the top 200 sources in the data set. Figure 4-2 in the main text of this report shows the distribution of SO_2 emissions in the previous data set.

A.2 Precipitation Chemistry Data

Four major precipitation chemistry networks are expected to be in operation providing event or daily samples for the foreseeable future. The number of stations involved provides a distribution of sites which are proposed for use in this experiment. A description of the data networks follows:

Multi-State Atmospheric Power Production Pollution Study (MAP3S)

The MAP3S precipitation chemistry network has been sponsored over the past seven years by the Environmental Protection Agency and the Department of Energy. The network currently consists of nine stations collecting event samples and hourly precipitation data. Precipitation samples are analyzed for:

- SO_2, $SO_4^=$, NO_2, NO_3^-, Cl^-, and $PO_4^=$
- H^+, NH_4^+, Na^+, K^+, Ca^{++}, Mg^{++}
- Conductivity

Station locations are given in Figure A-1.

The current MAP3S plans call for continued operation of the network through FY'85. Funding for the program is being transferred from EPA back to DOE, and it is not yet clear if operation will continue into FY'86 (Dana, 1984).

Utility Acid Precipitation Study Program (UAPSP)

The UAPSP precipitation chemistry network and its forerunner, the SURE program, have provided measurements since 1978. The current network consists of 19 sites collecting samples on an event basis with a daily sample collection during precipitation . Parameters analyzed include:

- precipitation amount
- pH, specific conductance, strong acids, total acids, total organic carbon
- $SO_4^=$, NO_3^-, Cl^-, $PO_4^=$, NH_4^+, NA^+, K^+, Ca^{++}, Mg^{++}, Al^{+++}

Current station locations are given in Figure A-1. Plans for the UAPSP network are for continued operation until May 1987, a projected date for the end of the MATEX program (Jansen, 1984).

Acidic Precipitation in Ontario Study (APIOS)

The Air Resources Branch of the Ontario Ministry of the Environment operates two networks under the APIOS program, a cumulative wet/dry deposition network and an event network (Chan et al., 1982). For the combined experiment, the most useful data would be obtained from the event network which provides daily samples of air quality parameters, precipitation, and precipitation chemistry. The distribution of sites is given in Figure A-1. These are in four major sampling areas in which four samplers operate in pairs. Spacing of the pairs is 50-100 km, and spacing between the paired sites is five to ten km. At one site, the pair of samplers is collocated to provide data for precision estimates. Parameters sampled at the APIOS event sites are:

- precipitation amounts
- pH, total acidity, and conductivity
- SO_4, $N\text{-}NO_3^-$, Cl^-, $N\text{-}NH_4^-$, Ca^{++}, Na^+, K^+, Mg^{++}

Precipitation chemistry measurements are supplemented by filter pack measurements of airborne $SO_4^=$, $N\text{-}NO_3$, $N\text{-}NH_4$, $N\text{-}HNO_3$, and SO_2.

It is expected that the APIOS precipitation chemistry network will be in operation during the proposed comprehensive experimental period (Chan, 1984).

Canadian Air and Precipitation Monitoring Network (CAPMoN)

The CAPMoN network has recently been established as a refinement of the CANSAP network operated by the Atmospheric Environment Service of Canada (Vet and Gilbert, 1984). The network which began operations in mid-1983 consists of approximately 20 sites in Eastern Canada, eight of which also serve as regional air quality monitoring sites. Five additional sites will be added shortly to the network. The locations of the eastern sites are given in Figure A-1.

Precipitation sampling in the CAPMoN network consists of automated wet only collection along with supplementary measurements of rain and snow. Samples are collected daily during precipitation periods. Air quality sampling includes filter pack measurements from 10 m which are changed weekly. The precipitation samples are analyzed for:

- pH, alkalinity/acidity
- SO_4^-, NO_3^-, Cl^-, NH_4^+, Ca^{++}, Mg^{++}, K^+, and Na^+

Air sampling by the filter packs are analyzed for particulate, $SO_4^=$, NO_3^-, NH_4^+, and gaseous SO_2 and HNO_3.

National Trends Network (NTN)

The National Trends Network is an atmoshperic deposition monitoring network designed to study the temporal and spatial trends in the chemical composition of wet and dry deposited pollutants. NTN is a long term continuation of the monitoring which took place under the National Atmospheric Deposition Program (NADP). The core of the program is a wet deposition monitoring network which includes 150 sites nationwide. Sampling on the network is for weekly periods although event sampling is possible. Analyses consider major ions in precipitation and precipitation amounts.

NTN programs also work toward improving techniques for sampling deposition. Some special research projects of the program include:

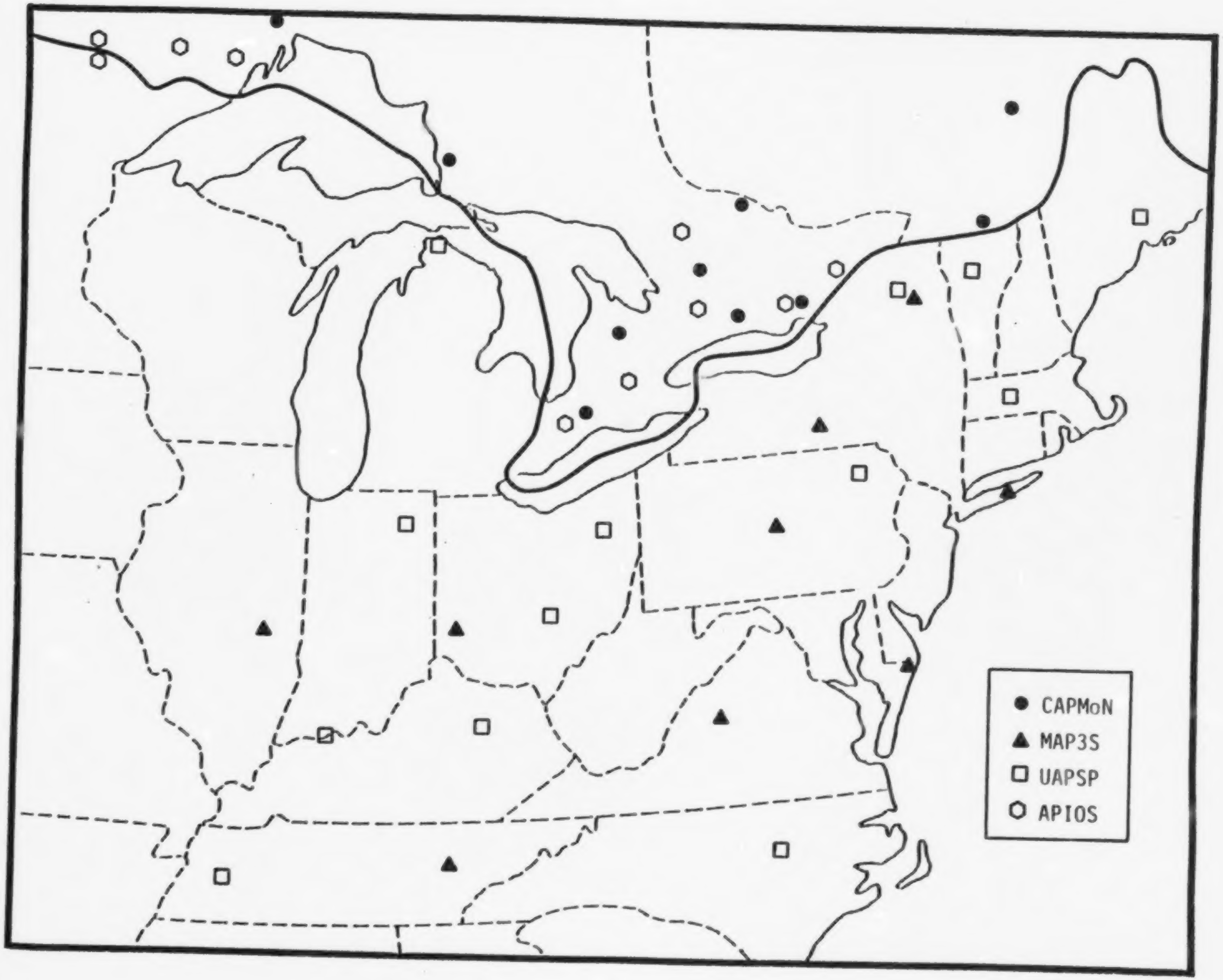
● CAPMoN
▲ MAP3S
□ UAPSP
⬡ APIOS

Figure A-1. Major event precipitation chemistry networks.

- monitoring in remote areas
- development of new collection, analysis, and siting criteria
- development and maintenance of a data system
- studies of spatial and temporal variability
- development of quality assurance techniques for precipitation chemistry monitoring networks
- studies of deposition effects
- developing methods of estimating accuracy and precision of measurements
- development of dry deposition monitoring techniques

NTN will provide estimates of dry deposition amounts at a limited number of network sites. The estimates will be made by applying deposition velocities to ambient concentration data collected at selected sites.

A.3 Land Use Data

Dry deposition rates are a function of surface type, and it is important to categorize the study area to generalize source/receptor relationships. Land use data for the Eastern U.S. and Canada are available. The NCAR data archive contains files of global vegetation, land-use, and land-cover data derived from maps and satellite imagery and analyzed in 1° intervals (Mathews, 1983). Data analyzed to 0.5° intervals were obtained for development of the Techniques Development Laboratory boundary layer model.

A.4 Meteorological Data

A large selection of meteorological data is available from the U.S. National Weather Service and the Atmospheric Environment Service of Canada. The primary data required for analysis experiments under this design are the regular rawinsonde observations of temperature, moisture and wind profiles.

These data are described in Section 6. Additional wind, radiation, moisture, temperature, precipitation, and cloud data as well as others will be necessary for regional model input and evaluation. Some important data of this type are fine mesh wind field model outputs, fine resolution precipitation data, and a complete file of surface synoptic observations. The individual needs of specific models vary and, as a result, data data requirements for evaluation of specific models are not discussed.

A.5 Related Research Studies

The study described in previous sections was designed to empirically answer questions of source attribution to acidic deposition rather than providing details on the processes governing deposition. Research in acidic deposition has traditionally followed a building block path with research on components or processes being pieced together to explain natural phenomena. Although the comprehensive experiment design is directed toward bypassing the process explanations, the availability of such information will contribute greatly to the analysis. Three programs which could potentially provide information to improve the comprehensive experiment are described below:

Processing of Emissions by Clouds and Precipitation (PRECP)

The PRECP study is an investigation of the non-linearities in acidic deposition processes. The study, sponsored by the U.S. Department of Energy, began in FY84 and will extend through FY90. The objectives of the plan as given by Michael (1984b) are:

> "To determine how wet deposition of acidic and other pollutants depends upon input to individual storms, by understanding the chemical and physical processing of emissions by clouds and precipitation, through an analysis of appropriate data, model development and testing, and laboratory and field studies, for applications in the definition of the relationships between pollutant releases and subsequent deposition."

The objectives will be approached by field, laboratory, and modeling studies addressing a series of questions relating to non-linear processes in the areas of:

- indicators found in historical data
- predictive ability
- the characteristics of cloud inflow regions
- in-cloud processes
- cloud dynamics and precipitation, and
- the characteristics of cloud outflow regions

The study is in its first or exploratory phase which will include laboratory, field, and modeling experiments designed to refine both hypotheses and measurement and analysis tools required for the study. The second phase will be the central phase in which questions of non-linearities of the processes will be answered. Further analyses going toward application of the study findings will take place in the last phase of the study. The interactions with the program and direct applicability of the project as a result of timing are difficult to determine. The first field experiments of the PRECP program will be in FY85. The plan for measurements and availability of the data have not been made public.

Acid Deposition Modeling Project

The National Center for Atmospheric Research Acid Deposition Modeling Project (ADMP) is a study sponsored by the U.S. Environmental Protection Agency to develop an improved model for simulating acidic deposition processes (NCAR, 1983a,b). The program also consists of a component which will develop an engineering model for assessment based on the more comprehensive research model. The multi-year study represents the major development project for deposition modeling in the U.S.

The modeling study as described in the design and management plan (NCAR, 1983b) will assemble a modeling system consisting of a meteorological model and a chemical transport module. The meteorological model initially proposed is a dynamical model for the Eastern U.S. consisting of 15 layers with a horizontal resolution of 80 km. The model will include parameterizations for planetary boundary layer processes and cumulus convection. Model inputs and derived variables include:

Basic Variables	Derived Variables
Horizontal wind components	Filtered (in space and time) wind components - for transport
Vertical wind component	Turbulence intensity
Pressure	3-D trajectories
Temperature	Cloud type, amount, and depth
Water vapor	Liquid water content
Precipitation amount	Height of planetary boundary layer
Surface fluxes of heat, moisture, and momentum	Relative humidity

The chemical/transport model shares the same grid resolution as the meteorological model with components including:

- an initialization scheme to input emissions and meteorological data and initialize chemical species data
- a module to develop chemical rate constants based on meteorological conditions
- a photochemical rate constant scheme
- a module for computation of dry deposition rates
- modules for transport/transformation calculations including deposition

Model outputs tentatively will include dry deposition estimates for HNO_3, H_2SO_4, aerosol sulfates, SO_2, NO_2, CH_2O, and other species and wet deposition estimates for H^+, HSO_3^-, $SO_4^=$, NO_3^-, NH_4^+, Ca^{++}, and Mg^{++}.

Stormscale Operational and Research Meteorology (STORM) Program

The STORM Program (NCAR, 1984) is a planned multi-year interagency program to study mesoscale convective systems or those precipitating systems which have horizontal scales of 10 to 500 km which also include significant convection sometime during their lifetime. The participating agencies include NOAA, NSF, NASA, and DOD. The mesoscale systems are thought to dominate the predicability of the weather when a warning of the most economically important events is required on time scale of hour to days and spatial scales of 2 to 2000 km.

The STORM study includes a significant meteorological measurements program and modeling to explain and predict mesoscale systems. Intensive measurement programs are planned for the central, eastern, and western portions of the country beginning with studies in the central states under a program called STORM-Central.

The focus of both the operational and research components of STORM-Central will be the mesoscale convective system (MCS), which is responsible for most of the beneficial rainfall and nearly all of the threatening weather (heavy rains, high winds, flash floods, tornadoes, and dangerous wind shears) that occur in the United States in spring and summer.

The research goals of STORM-Central are focused on the basic knowledge of MCS's required for the improvement of forecasts. The operational objectives are more specific, aimed at early testing and evaluation of improved observing tools on the mesoscale and effective ways to use them in the forecasting of mesoscale precipitation and severe weather events. A mechanism in achieving these goals will be experimental forecast centers, where operational forecasters and research scientists will work together to develop, test, and evaluate analysis, forecasting, and dissemination techniques.

The field phase of STORM-Central will be conducted during the four-month period, April-July, 1988. Its focal point will be a meso-alpha-scale network covering the central one-third of the United States from the gulf Coast to Canada and from the Rockies to the central Ohio Valley, within which the large mesoscale phenomena responsible for triggering significant weather will be well observed by an upper-air sounding system with a resolution of 200 km. Many of the new instruments to be employed in the system are capable of near-continuous observations. Embedded within this larger network will be a meso-beta-scale network capable of observing all convective and precipitation events by radar, with upper-air soundings made more frequently and at 100 km resolution, and with automated surface observations made at 40 km resolution. Experimental forecasting will be focused on the meso-beta network. The central part of this area, which will include a Doppler radar array capable of observing the internal structure of MCS's, is where severe weather research and forecasting activities will be concentrated.

Many of the resources required for STORM are now in existence and will be provided by the participating agencies, along with many regular staff members. These existing resources include aircraft, satellites, and radars. A sizeable number of new capital resources are also required. These included new Doppler radars, new inexpensive lightweight balloon systems to take vertical soundings, improved dropwindsondes for release from aircraft, and profilers (automated ground-base Doppler radar systems) that can measure winds continuously as a function of height above a fixed site. The profilers are in the stage of advanced development. This effort requires new resources for development and procurement if profilers are to be available for STORM-Central.

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APPENDIX B

WORKSHOP ATTENDEES

Norman Bowne, TRC Environmental Consultants (TRC)
Daniel McNaughton, TRC
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Donald Shearer, TRC
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Stanley Greenfield, SAI
Steven Reynolds, SAI
Gary Whitten, SAI
Christian Seigneur, SAI
Douglas Stewart, SAI
Frank Murray, RAND Corp.
Boris Weisman, MEP Co.
Don Stedman, University of Denver
Francis Pooler, NOAA/EPA
Jack Durham, EPA
Frank Binkowski, NOAA/EPA
Richard Kerch, Consolidation Coal Co.
Art Bass, Environmental Research and Technology
Stephen Schwartz, Brookhaven National Laboratory (BNL)
Leonard Newman, BNL
Gunnar Senum, BNL
Ari Patrinos, BNL
Paul Michael, BNL
Gilbert Raynor, BNL
Russel Dietz, BNL
Roger Tanner, BNL
Peter Daum, BNL
Nels Laulainen, Pacific Northwest Laboratory (PNL)
Mort Barad, BCI